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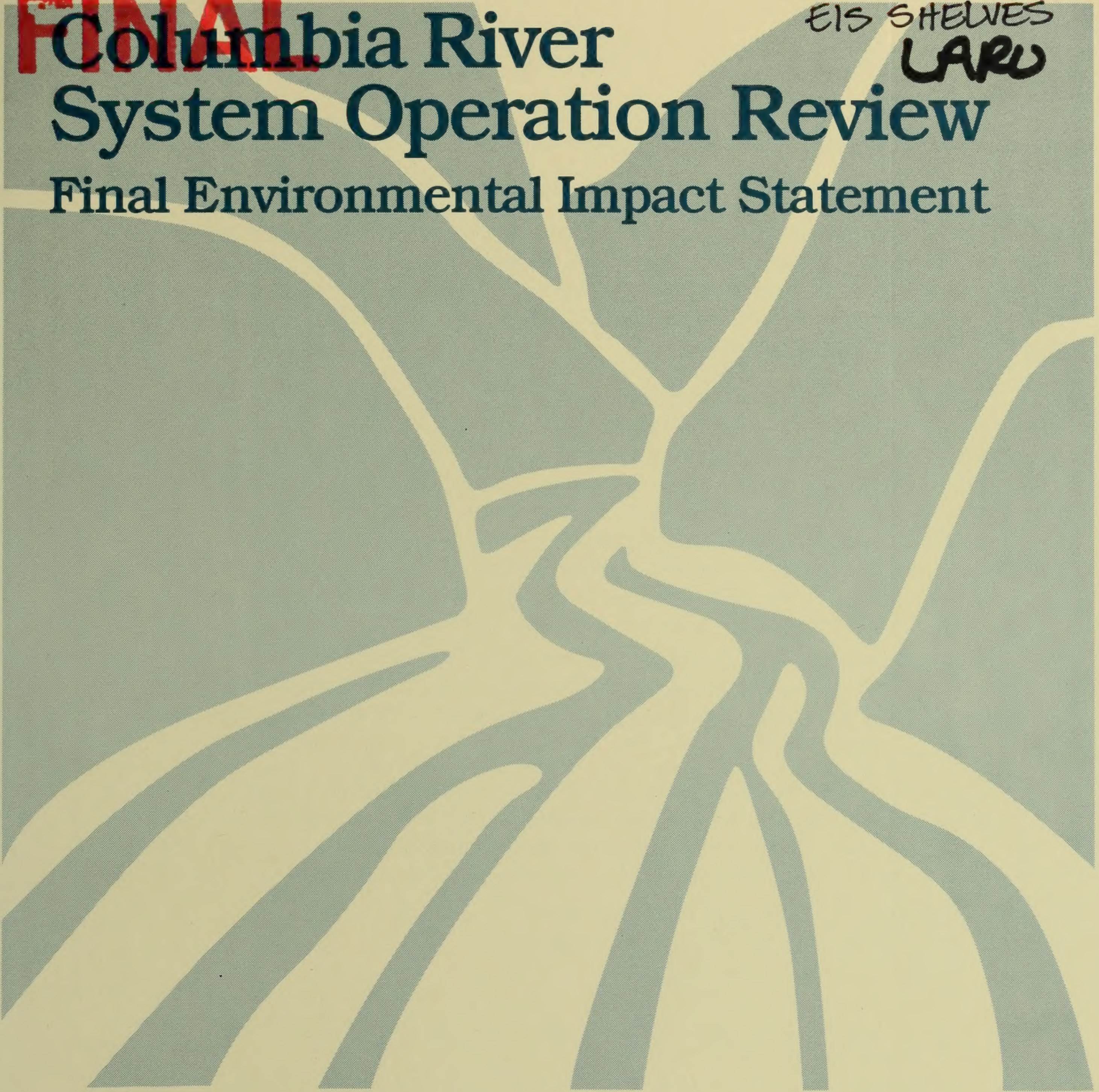
# Columbia River System Operation Review

## Final Environmental Impact Statement



## Appendix M

### Water Quality

BONNEVILLE POWER ADMINISTRATION

US Army Corps of Engineers
North Pacific Division

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

**DOE/EIS-0170**

**November 1995**

## PUBLIC INVOLVEMENT IN THE SOR PROCESS

The Bureau of Reclamation, Corps of Engineers, and Bonneville Power Administration wish to thank those who reviewed the Columbia River System Operation Review (SOR) Draft EIS and appendices for their comments. Your comments have provided valuable public, agency, and tribal input to the SOR NEPA process. Throughout the SOR, we have made a continuing effort to keep the public informed and involved.

Fourteen public scoping meetings were held in 1990. A series of public roundtables was conducted in November 1991 to provide an update on the status of SOR studies. The lead agencies went back to most of the 14 communities in 1992 with 10 initial system operating strategies developed from the screening process. From those meetings and other consultations, seven SOS alternatives (with options) were developed and subjected to full–scale analysis. The analysis results were presented in the Draft EIS released in July 1994. The lead agencies also developed alternatives for the other proposed SOR actions, including a Columbia River Regional Forum for assisting in the determination of future SOSs, Pacific Northwest Coordination Agreement alternatives for power coordination, and Canadian Entitlement Allocation Agreements alternatives. A series of nine public meetings was held in September and October 1994 to present the Draft EIS and appendices and solicit public input on the SOR. The lead agencies received 282 formal written comments. Your comments have been used to revise and shape the alternatives presented in the Final EIS.

Regular newsletters on the progress of the SOR have been issued. Since 1990, 20 issues of *Streamline* have been sent to individuals, agencies, organizations, and tribes in the region on a mailing list of over 5,000. Several special publications explaining various aspects of the study have also been prepared and mailed to those on the mailing list. Those include:

The Columbia River: A System Under Stress
The Columbia River System: The Inside Story
Screening Analysis: A Summary
Screening Analysis: Volumes 1 and 2
Power System Coordination: A Guide to the Pacific Northwest Coordination Agreement
Modeling the System: How Computers are Used in Columbia River Planning
Daily/Hourly Hydrosystem Operation: How the Columbia River System Responds to Short–Term Needs

Copies of these documents, the Final EIS, and other appendices can be obtained from any of the lead agencies, or from libraries in your area.

Your questions and comments on these documents should be addressed to:

SOR Interagency Team
P .O. Box 2988
Portland, OR 97208–2988

## PREFACE: SETTING THE STAGE FOR THE SYSTEM OPERATION REVIEW

### WHAT IS THE SOR AND WHY IS IT BEING CONDUCTED?

The Columbia River System is a vast and complex combination of Federal and non–Federal facilities used for many purposes including power production, irrigation, navigation, flood control, recreation, fish and wildlife habitat and municipal and industrial water supply. Each river use competes for the limited water resources in the Columbia River Basin.

To date, responsibility for managing these river uses has been shared by a number of Federal, state, and local agencies. Operation of the Federal Columbia River system is the responsibility of the Bureau of Reclamation (Reclamation), Corps of Engineers (Corps) and Bonneville Power Administration (BPA).

The System Operation Review (SOR) is a study and environmental compliance process being used by the three Federal agencies to analyze future operations of the system and river use issues. The goal of the SOR is to achieve a coordinated system operation strategy for the river that better meets the needs of all river users. The SOR began in early 1990, prior to the filing of petitions for endangered status for several salmon species under the Endangered Species Act.

The comprehensive review of Columbia River operations encompassed by the SOR was prompted by the need for Federal decisions to (1) develop a coordinated system operating strategy (SOS) for managing the multiple uses of the system into the 21st century; (2) provide interested parties with a continuing and increased long–term role in system planning (Columbia River Regional Forum); (3) renegotiate and renew the Pacific Northwest Coordination Agreement (PNCA), a contractual arrangement among the region's major hydroelectric–generating utilities and affected Federal agencies to provide for coordinated power generation on the Columbia River system; and (4) renew or develop new Canadian Entitlement Allocation Agreements (contracts that divide Canada's share of Columbia River Treaty downstream power benefits and obligations among three participating public utility districts and BPA). The review provides the environmental analysis required by the National Environmental Policy Act (NEPA).

This technical appendix addresses only the effects of alternative system operating strategies for managing the Columbia River system. The environmental impact statement (EIS) itself and some of the other appendices present analyses of the alternative approaches to the other three decisions considered as part of the SOR.

### WHO IS CONDUCTING THE SOR?

The SOR is a joint project of Reclamation, the Corps, and BPA—the three agencies that share responsibility and legal authority for managing the Federal Columbia River System. The National Marine Fisheries Service (NMFS), U.S. Fish and Wildlife Service (USFWS), and National Park Service (NPS), as agencies with both jurisdiction and expertise with regard to some aspects of the SOR, are cooperating agencies. They contribute information, analysis, and recommendations where appropriate. The U.S. Forest Service (USFS) was also a cooperating agency, but asked to be removed from that role in 1994 after assessing its role and the press of other activities.

### HOW IS THE SOR BEING CONDUCTED?

The system operating strategies analyzed in the SOR could have significant environmental impacts. The study team developed a three–stage process—scoping, screening, and full–scale analysis of the strategies—to address the many issues relevant to the SOR.

At the core of the analysis are 10 work groups. The work groups include members of the lead and cooperating agencies, state and local government agencies, representatives of Indian tribes, and members of the public. Each of these work groups has a single river use (resource) to consider.

Early in the process during the screening phase, the 10 work groups were asked to develop an alternative for project and system operations that would provide the greatest benefit to their river use, and one or more alternatives that, while not ideal, would provide an acceptable environment for their river use. Some groups responded with alternatives that were evaluated in this early phase and, to some extent, influenced the alternatives evaluated in the Draft and Final EIS. Additional alternatives came from scoping for the SOR and from other institutional sources within the region. The screening analysis studied 90 system operation alternatives.

Other work groups were subsequently formed to provide projectwide analysis, such as economics, river operation simulation, and public involvement.

The three–phase analysis process is described briefly below.

- **Scoping/Pilot Study**—After holding public meetings in 14 cities around the region, and coordinating with local, state, and Federal agencies and Indian tribes, the lead agencies established the geographic and jurisdictional scope of the study and defined the issues that would drive the EIS. The geographic area for the study is the Columbia River Basin (Figure P–1). The jurisdictional scope of the SOR encompasses the 14 Federal projects on the Columbia and lower Snake Rivers that are operated by the Corps and Reclamation and coordinated for hydropower under the PNCA. BPA markets the power produced at these facilities. A pilot study examining three alternatives in four river resource areas was completed to test the decision analysis method proposed for use in the SOR.
- **Screening**—Work groups, involving regional experts and Federal agency staff, were created for 10 resource areas and several support functions. The work groups developed computer screening models and applied them to the 90 alternatives identified during screening. They compared the impacts to a baseline operating year—1992—and ranked each alternative according to its impact on their resource or river use. The lead agencies reviewed the results with the public in a series of regional meetings in September 1992.
- **Full–Scale Analysis**—Based on public comment received on the screening results, the study team sorted, categorized, and blended the alternatives into seven basic types of operating strategies. These alternative strategies, which have multiple options, were then subjected to detailed impact analysis. Twenty–one possible options were evaluated. Results and tradeoffs for each resource or river use were discussed in separate technical appendices and summarized in the Draft EIS. Public review and comment on the Draft EIS was conducted during the summer and fall of 1994. The lead agencies adjusted the alternatives based on the comments, eliminating a few options and substituting new options, and reevaluated them during the past 8 months. Results are summarized in the Final EIS.

Alternatives for the Pacific Northwest Coordination Agreement (PNCA), the Columbia River Regional Forum (Forum), and the Canadian Entitlement Allocation Agreements (CEAA) did not use the three–stage process described above. The environmental impacts from the PNCA and CEAA were not significant and there were no anticipated impacts from the Regional Forum. The procedures used to analyze alternatives for these actions are described in their respective technical appendices.

For detailed information on alternatives presented in the Draft EIS, refer to that document and its appendices.

## WHAT SOS ALTERNATIVES ARE CONSIDERED IN THE FINAL EIS?

Seven alternative System Operating Strategies (SOS) were considered in the Draft EIS. Each of the seven SOSs contained several options bringing the total number of alternatives considered to 21. Based on review of the Draft EIS and corresponding adjustments, the agencies have identified 7 operating strategies that are evaluated in this Final EIS. Accounting for options, a total of 13 alternatives is now under consideration. Six of the alternatives remain unchanged from the specific options considered in the Draft EIS. One is a revision to a previously considered alternative, and the rest represent replacement or new alternatives. The basic categories of SOSs and the numbering convention remains the same as was used in the Draft EIS. However, because some of the alternatives have been dropped, the numbering of the final SOSs are not consecutive. There is one new SOS category, Settlement Discussion Alternatives, which is labeled SOS 9 and replaces the SOS 7 category. This category of alternatives arose as a consequence of litigation on the 1993 Biological Opinion and ESA Consultation for 1995.

The 13 system operating strategies for the Federal Columbia River system that are analyzed for the Final EIS are:

**SOS 1a Pre Salmon Summit Operation** represents operations as they existed from around 1983 through the 1990–91 operating year, prior to the ESA listing of three species of salmon as endangered or threatened.

**SOS 1b Optimum Load–Following Operation** represents operations as they existed prior to changes resulting from the Regional Act. It attempts to optimize the load–following capability of the system within certain constraints of reservoir operation.

**SOS 2c Current Operation/No–Action Alternative** represents an operation consistent with that specified in the Corps of Engineers' 1993 Supplemental EIS. It is similar to system operation that occurred in 1992 after three species of salmon were listed under ESA.

**SOS 2d [New] 1994–98 Biological Opinion** represents the 1994–98 Biological Opinion operation that includes up to 4 MAF flow augmentation on the Columbia, flow targets at McNary and Lower Granite, specific volume releases from Dworshak, Brownlee, and the Upper Snake, meeting sturgeon flows 3 out of 10 years, and operating lower Snake projects at MOP and John Day at MIP.

**SOS 4c [Rev.] Stable Storage Operation with Modified Grand Coulee Flood Control** attempts to achieve specific monthly elevation targets year round that improve the environmental conditions at storage projects for recreation, resident fish, and wildlife. Integrated Rules Curves (IRCs) at Libby and Hungry Horse are applied.

**SOS 5b Natural River Operation** draws down the four lower Snake River projects to near river bed levels for four and one–half months during the spring and summer salmon migration period, by assuming new low level outlets are constructed at each project.

**SOS 5c [New] Permanent Natural River Operation** operates the four lower Snake River projects to near river bed levels year round.

**SOS 6b Fixed Drawdown Operation** draws down the four lower Snake River projects to near spillway crest levels for four and one–half months during the spring and summer salmon migration period.

**SOS 6d Lower Granite Drawdown Operation** draws down Lower Granite project only to near spillway crest level for four and one–half months.

**SOS 9a [New] Detailed Fishery Operating Plan** includes flow targets at The Dalles based on the previous year's end–of–year storage content, specific volumes of releases for the Snake River, the drawdown of Lower Snake River projects to near spillway crest level for four and one–half months, specified spill percentages, and no fish transportation.

**SOS 9b [New] Adaptive Management** establishes flow targets at McNary and Lower Granite based on runoff forecasts, with specific volumes of releases to meet Lower Granite flow targets and specific spill percentages at run–of–river projects.

**SOS 9c [New] Balanced Impacts Operation** draws down the four lower Snake River projects near spillway crest levels for two and one–half months during the spring salmon migration period. Refill begins after July 15. This alternative also provides 1994–98 Biological Opinion flow augmentation, integrated rule curve operation at Libby and Hungry Horse, a reduced flow target at Lower Granite due to drawdown, winter drawup at Albeni Falls, and spill to achieve no higher than 120 percent daily average for total dissolved gas.

**SOS PA Preferred Alternative** represents the operation proposed by NMFS and USFWS in their Biological Opinions for 1995 and future years; this SOS operates the storage projects to meet flood control rule curves in the fall and winter in order to meet spring and summer flow targets for Lower Granite and McNary, and includes summer draft limits for the storage projects.

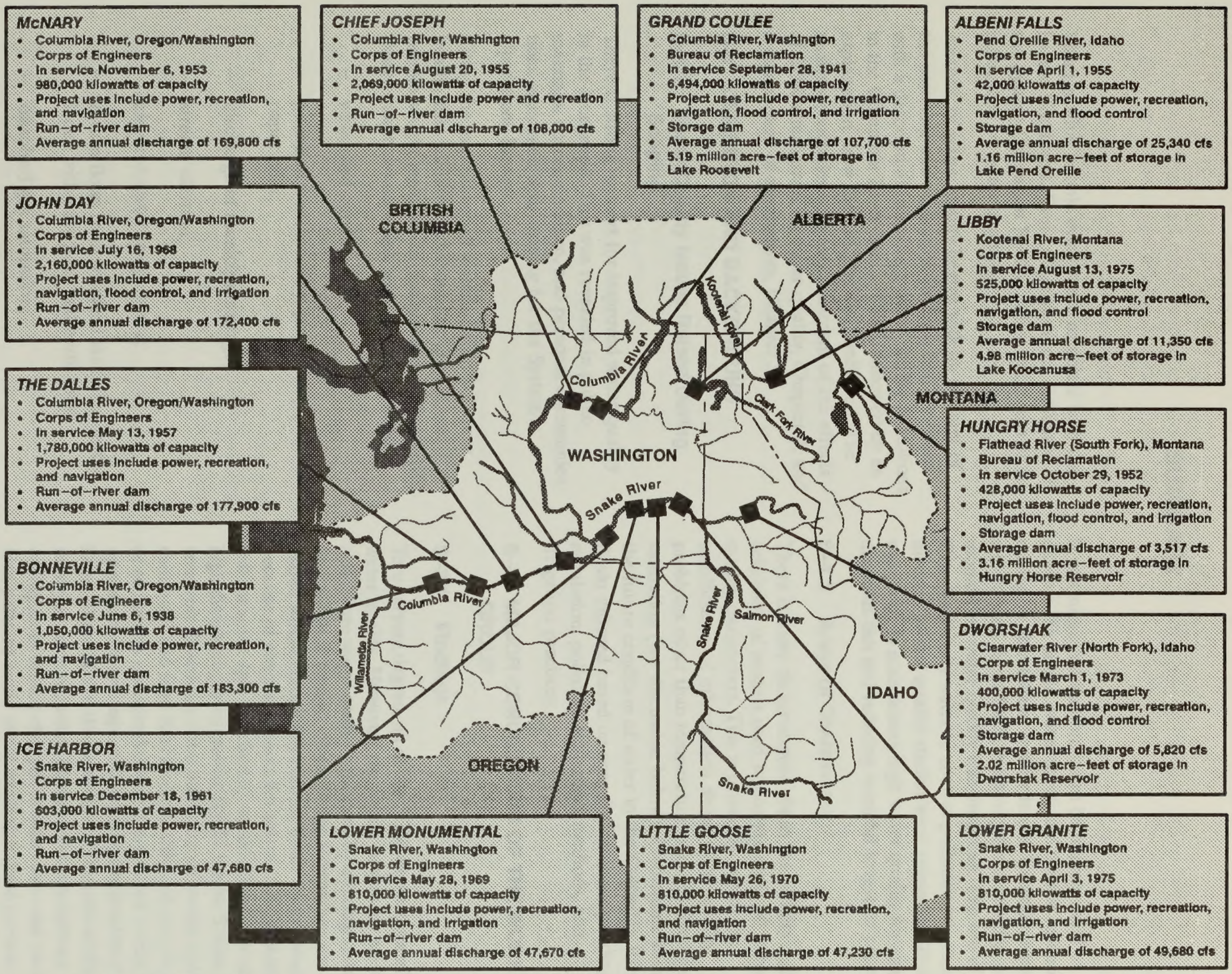
## WHAT DO THE TECHNICAL APPENDICES COVER?

This technical appendix is 1 of 20 prepared for the SOR. They are:

A. River Operation Simulation
B. Air Quality
C. Anadromous Fish & Juvenile Fish Transportation
D. Cultural Resources
E. Flood Control
F. Irrigation/Municipal and Industrial Water Supply
G. Land Use and Development
H. Navigation
I. Power
J. Recreation
K. Resident Fish
L. Soils, Geology, and Groundwater
M. Water Quality
N. Wildlife
O. Economic and Social Impacts
P. Canadian Entitlement Allocation Agreements
Q. Columbia River Regional Forum
R. Pacific Northwest Coordination Agreement
S. U. S. Fish and Wildlife Service Coordination Act Report
T. Comments and Responses

Each appendix presents a detailed description of the work group's analysis of alternatives, from the scoping process through full–scale analysis. Several appendices address specific SOR functions (e.g., River Operation Simulation), rather than individual resources, or the institutional alternatives (e.g., PNCA) being considered within the SOR. The technical appendices provide the basis for developing and analyzing alternative system operating strategies in the EIS. The EIS presents an integrated review of the vast wealth of information contained in the appendices, with a focus on key issues and impacts. In addition, the three agencies have prepared a brief summary of the EIS to highlight issues critical to decision makers and the public.

There are many interrelationships among the different resources and river uses, and some of the appendices provide supporting data for analyses presented in other appendices. This Water Quality appendix relies on supporting data contained in Appendices H and O. For complete coverage of all aspects of water quality, readers may wish to review all three appendices in concert.



**McNARY**
- Columbia River, Oregon/Washington
- Corps of Engineers
- In service November 6, 1953
- 980,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 169,800 cfs

**CHIEF JOSEPH**
- Columbia River, Washington
- Corps of Engineers
- In service August 20, 1955
- 2,069,000 kilowatts of capacity
- Project uses include power and recreation
- Run–of–river dam
- Average annual discharge of 108,000 cfs

**GRAND COULEE**
- Columbia River, Washington
- Bureau of Reclamation
- In service September 28, 1941
- 6,494,000 kilowatts of capacity
- Project uses include power, recreation, navigation, flood control, and irrigation
- Storage dam
- Average annual discharge of 107,700 cfs
- 5.19 million acre–feet of storage in Lake Roosevelt

**ALBENI FALLS**
- Pend Oreille River, Idaho
- Corps of Engineers
- In service April 1, 1955
- 42,000 kilowatts of capacity
- Project uses include power, recreation, navigation, and flood control
- Storage dam
- Average annual discharge of 25,340 cfs
- 1.16 million acre–feet of storage in Lake Pend Oreille

**JOHN DAY**
- Columbia River, Oregon/Washington
- Corps of Engineers
- In service July 16, 1968
- 2,160,000 kilowatts of capacity
- Project uses include power, recreation, navigation, flood control, and irrigation
- Run–of–river dam
- Average annual discharge of 172,400 cfs

**LIBBY**
- Kootenai River, Montana
- Corps of Engineers
- In service August 13, 1975
- 525,000 kilowatts of capacity
- Project uses include power, recreation, navigation, and flood control
- Storage dam
- Average annual discharge of 11,350 cfs
- 4.98 million acre–feet of storage in Lake Koocanusa

**THE DALLES**
- Columbia River, Oregon/Washington
- Corps of Engineers
- In service May 13, 1957
- 1,780,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 177,900 cfs

**HUNGRY HORSE**
- Flathead River (South Fork), Montana
- Bureau of Reclamation
- In service October 29, 1952
- 428,000 kilowatts of capacity
- Project uses include power, recreation, navigation, flood control, and irrigation
- Storage dam
- Average annual discharge of 3,517 cfs
- 3.16 million acre–feet of storage in Hungry Horse Reservoir

**BONNEVILLE**
- Columbia River, Oregon/Washington
- Corps of Engineers
- In service June 6, 1938
- 1,050,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 183,300 cfs

**DWORSHAK**
- Clearwater River (North Fork), Idaho
- Corps of Engineers
- In service March 1, 1973
- 400,000 kilowatts of capacity
- Project uses include power, recreation, navigation, and flood control
- Storage dam
- Average annual discharge of 5,820 cfs
- 2.02 million acre–feet of storage in Dworshak Reservoir

**ICE HARBOR**
- Snake River, Washington
- Corps of Engineers
- In service December 18, 1961
- 603,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 47,680 cfs

**LOWER MONUMENTAL**
- Snake River, Washington
- Corps of Engineers
- In service May 28, 1969
- 810,000 kilowatts of capacity
- Project uses include power, recreation, navigation, and irrigation
- Run–of–river dam
- Average annual discharge of 47,670 cfs

**LITTLE GOOSE**
- Snake River, Washington
- Corps of Engineers
- In service May 26, 1970
- 810,000 kilowatts of capacity
- Project uses include power, recreation, and navigation
- Run–of–river dam
- Average annual discharge of 47,230 cfs

**LOWER GRANITE**
- Snake River, Washington
- Corps of Engineers
- In service April 3, 1975
- 810,000 kilowatts of capacity
- Project uses include power, recreation, navigation, and irrigation
- Run–of–river dam
- Average annual discharge of 49,680 cfs

1 million acre feet = 1.234 billion cubic meters
1 cubic foot per second = 0.028 cubic meters per second

Figure P–1. Projects in the System Operation Review.

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# SUMMARY

Water is what people everywhere associate with the Pacific Northwest. Every other resource evaluated in the System Operation Review either influences or is influenced by water quality.

Analysis of water quality begins with an account of the planning and evaluation process, and continues with a description of existing water quality conditions in the Columbia River Basin. This is followed by an explanation how the analysis was conducted. The analysis concludes with an assessment of the effects of SOR alternatives on water quality, Chapter 4, and a comparison of alternatives, Chapter 5.

## S–1 DEFINITION AND BACKGROUND

### S–1.1 Water Quality Issues Raised During Scoping

There is strong support for improved water quality in the Northwest. This was revealed in public meetings, correspondence, and personal communications associated with scoping for the System Operations Review.

Citing the importance of water quality to human health, fish, wildlife, and economic growth, many people sought inclusion of the resource in the SOR. Water quality issues which were raised included:

- watershed conditions;
- pollution from industry, particularly pulp and paper mills;
- discharge of municipal sewage;
- stream siltation;
- elevated water temperature;
- return flows from irrigated land, frequently laden with pesticides and herbicides;
- dissolved gas saturation;
- condition of domestic drinking water.

It was suggested that programs be implemented to educate the public, water users, and natural resource managers about water quality issues. Establishment of a Columbia River Basin Authority for measuring and monitoring water quality was proposed. The use of Canadian treaty water to control pollution was recommended. Water quality studies were requested. Priority was given to maintaining high water quality for anadromous fish and reducing wasteful irrigation practices.

### S–1.2 Areas of Controversy

There is some disagreement about the validity and reliability of models used to analyze some 30 water quality parameters. This is primarily due to the insufficiency of information about water quality problems other than temperature and dissolved gas saturation (see discussion below). Predictions about the future condition of water in the Columbia River Basin differed based on speculation about pending regulation, pollution abatement methods, and irrigation practices.

## S–2 MAJOR CONCLUSIONS OF THE WORK GROUP

### S–2.1 Findings

To a varying degree, all of the SOR alternatives affect water quality. However, the ability to remedy existing and future water quality problems by altering system operations is limited. None of the alternatives evaluated would completely control water temperature, because of physical project limitation. All alternatives call for some spill and, hence, would continue to cause high dissolved gas saturation levels. Lower Snake River reservoir drawdown alternatives would create significant bank and mud flats erosion, although the impacts of sediments resuspended and transported during this operation are not expected to extend beyond McNary Dam. None of the alternatives would create additional dredging for navigation. Many of the alternatives calling from drastic changes in water flow and circulation patterns could affect existing federal permits issued under NPDES and the Clean Water Act.

Predicted water quality impacts are graphically summarized in Figure 5–5 on page 5–17.

### S–2.2 Choice Among Alternatives

Adverse impacts on water temperature could be reduced if enough cool water was stored in reservoirs for use in the summer season. Dissolved gas supersaturation problems would not exist if spill could be eliminated entirely. Sediment transport and high turbidity would not occur if reservoir pools did not fluctuate below normal operating range, leaving normally submerged banks exposed to the natural elements. Most water quality problems would not be serious if sufficient flows could be maintained year–round to dilute or assimilate contaminants.

A water quality alternative meeting all these requirements could not be formulated because of the physical properties of structures on the river and conflicts in the requirements of different water users. Although slightly more favorable conditions were observed for water temperature and total dissolved gas in pre–Endangered Species Act operations than in the base case alternatives, only the natural river options produced more visible improvements in those two areas.

The natural river option imposes no restriction on flow and sediment movement and, therefore, eliminates spill during the time window the Lower Snake River reservoirs are drawdown to river bed level. It can still rely on headwater storage projects to provide sustained minimum flows. Increased bank and mud flats erosion and sediment transport, however, would increase turbidity, and nutrients and contaminants concentration in the lower Snake River and further downstream for some period of time. Providing the required bank protection and coping with increased sediment loading could be cost–prohibitive.

Given these considerations, a combination of alternatives built around the natural river option is more likely to be best for water quality. Any such combination would need to take into account impacts to other water users as well. Even within a given alternative, system regulation during extreme flow years may need to be different from that used in an average year, because of variability in water quality data.

### S–2.3 Recommendations for Future Study or Referral to Appropriate Agencies

1. A more comprehensive, whole river water quality study of the Columbia River Basin would fill current knowledge gaps and increase the chance of success of future water quality improvement programs. There is a continuing need to know and to closely monitor progress made in protecting and enhancing water quality in the Pacific Northwest.

   The absence of data was particularly acute in the realm of industrial and agricultural pollution. Information about the concentrations and possible movement of trace metals, dioxin, radionuclides, fertilizer, and pesticides is incomplete or missing. The return of water into the river from irrigated agricultural lands is a major concern. Insufficient data made reliable modelling of these problems difficult or impossible. Also needed is a better understanding of the interaction of contaminants and river processes. Recommendations for improving these limitations are given in Chapter 5.

2. Mitigation measures to minimize adverse impacts on fish and aquatic life should include facilities to reduce water temperature and total dissolved gas saturation, where feasible, and new strategies for protecting anadromous fish during periods of high water temperature and high dissolved gas saturation.

3. Since water quality problems are caused by sources both internal and external to the streams, they should be resolved jointly by project owners and operators; relevant state, municipal, and federal regulatory agencies; and the public. Point and nonpoint source and extra–basin pollution, and dredging requirements for navigation need to be taken into account. Education programs are needed to improve public understanding of reservoir operating policies and regional and local issues.

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# CHAPTER 1

# SCOPE AND PROCESS

## 1.1 IDENTIFICATION OF WATER QUALITY ISSUES

Because water is the element upon which the river system operates, an assessment of water quality has very broad implication. Water quality issues for analysis in the SOR emerged from three sources:

1. written accounts of known water quality problems in the media or scientific literature;
2. public comment at SOR scoping and coordination meetings;
3. a survey of federal, state, county, and local agencies in the Columbia River Basin.

Once defined, these issues were considered at length by regional technical water quality specialists participating in the SOR Water Quality Work Group.

### 1.1.1 Known Historical Water Quality Issues

Concern about degradation of water quality in the Columbia River Basin began in the 1930s. Hydropower development, irrigated agriculture, logging, mining, stream channelization, and urbanization were contributing factors. The following abstract from a recent paper by Stober and Nakatani published in Water Quality in North American River Systems, Battelle Press, 1992 summarizes many of the central issues:

"Hydroelectric and agricultural development has changed the quantity and timing of seasonal run–off. Impoundments have modulated temperature extremes in the main stem, delaying the annual thermal maximum below Grand Coulee about 30 days. Warm temperature occurs seasonally at the mouths of tributaries, which may delay the return of adult salmonids to spawning grounds. High spill at dams may supersaturate the river water with air and cause gas bubble diseases in fish.

"Dissolved oxygen levels are adequate in the main stem Columbia River but have been depressed in some tributaries by irrigation withdrawal and returns, and by waste loads from municipal and industrial activities. Specific conductance, nitrate–nitrite, sodium, sulfate, chloride, and temperature in the main stem generally increase downstream. The Snake and Willamette rivers account for the major input of total nitrogen and phosphorus to the Columbia River. Suspended sediment tends to increase in subbasins with logging and agriculture. Seasonal turbidity from suspended sediments has declined in the main stem since the mid–1950s because of impoundments. Toxic chemicals (pesticides, PCBs, and trace metals) have been found in fish of the Columbia River Basin, resulting in at least one recent human health advisory".

### 1.1.2 Water Quality issues raised by the public and agency coordination.

#### 1.1.2.1 Public Scoping

The SOR Interagency Team conducted 14 meetings throughout the Pacific Northwest during the summer of 1990. During and after these meetings, the public responded in oral testimonies, letters, comment cards, and transcription of small group sessions. The following issues, concerns, and ideas are excerpted from the Comment Summary prepared in January 1991 by the SOR Interagency Team:

- water quality must be part of SOR (Lake Spokane Association, King Hill Irrigation District, Trout Unlimited, U.S. Soil Conservation Service);
- continued support of water quality programs to better educate water users and managers (Riverview Grange);

- mitigate stream siltation and chemical pollution; develop an educational program on the enhancement of water quality in watersheds;
- water quality is important to wildlife;
- water quality and anadromous fish runs are most important concerns;
- the biggest eutrophication problem was at Hanford, when hot water was expelled;
- industrial and non–industrial pollution must be stopped if all of the benefits of the Columbia are to be maintained;
- the priority must be to keep the river clean;
- SOR process needs to include water quality decisions;
- to prepare for twice as many people in the year 2030, a Columbia River Basin Water Quality Authority must be established to measure and monitor water quality;
- the water quality of the Columbia River must be maintained and in some cases improved (Bureau of Indian Affairs);
- no more discharges of radioactive wastes from Hanford and marine effluents; sewage and the like should not be allowed to further pollute the waters;
- system should be managed so as to maintain and enhance water quality and fish and wildlife habitat (University of Montana);
- Libby dam's selective withdrawal system should be used and the [Kootenai] river be kept at optimal temperature for [resident] fishery improvement (Kootenai Fly Fishers);
- ecosystem alteration is irreversible when egg, fry, and smolt exposure to fungal, bacterial, and viral pathogens cannot be mitigated because of inadequate water movement, high water temperatures, and changes in water quality;
- hot water released by Hanford, fertilization, accumulation of pesticides, mining, stripping forests, and other large sources of point pollution harm salmon;
- reservoir drawdown alternatives should include flushing rates over the dam under different drawdown and water retention time conditions (Upper Columbia Tribes);
- water budget and spill plans and other flow regimes have a significant effect on river management;
- good Clearwater River flows are needed for dispersal of effluent from pulp and paper operations: if a conflict develops with maintaining high Dworshak reservoir levels, flows for effluent dispersal should take precedence (Potlach Corp.);
- exposed sand bars and mud flats, undercut cliffs, and eroded banks make Lake Roosevelt dangerous during periods of low water; turbid water makes the lake dangerous during high water (Stevens County Assessor);
- any redirected waters back to the Columbia should be carefully monitored for pollutants as well as temperature, flow changes, or diversion techniques; such clean–up would include getting rid of pesticides and herbicides, phosphate and nitrates, and industrial wastes, especially dioxins from pulp mills;
- stringent habitat, land use, conservation, pollution control, and education programs should be developed within each watershed to mitigate stream siltation, chemical pollution, and flooding;
- fish and wildlife needs should be built in as hard constraints in the long–term plan of operation (U.S. Fish and Wildlife Service);
- consultation with agencies that are mandated by [Montana] state law to administer water management programs needs to be part of the review (Montana Department of Natural Resources);

- agriculture and aquaculture returns are putting an enormous silt and nutrient load [on the Snake River between Milner and Bliss dams] and the dams have blocked much of the rivers natural flushing action (Wood River Resource Conservation);

- point discharge on the system and Canada is still raw sewage;

- use of treaty with Canada should also incorporate pollution control along the Columbia River (Lake Spokane Protective Association);

- study as to why the algae is taking over the Snake River (King Hill Irrigation District).

There were additional public comments during the 14 SOR Mid–Point Review Public Meetings held in the fall of 1992. Sixty–six written testimonies and 136 comment sheets were received from the public. Issues raised at these meetings included the need to maintain high water quality to protect anadromous fish, and increased water conservation to limit wasteful irrigation practices.

#### 1.1.2.2 Agency Water Quality Letter Survey of Professionals

The water quality work group conducted a limited letter survey of regional government agencies involved in water quality. Respondents were asked to identify and rank 20 contaminants and physical parameters from a list of 50. The list included the following groups: conventional parameters, toxic chemicals in water and sediments, semi–volatiles, nutrients, bacteria, and radionuclides. Seven river reaches were considered:

1. International border to Grand Coulee Dam (Columbia)

2. Grand Coulee Dam to Snake River confluence (Columbia)

3. Snake River confluence to Bonneville Dam (Columbia)

4. Snake River

5. Yakima River

6. Willamette River

7. Bonneville Dam to the Pacific Ocean (Columbia)

The most important parameters from the list of 50 were ranked from 1 to 20, most to least important. The resulting weighted averages are summarized in Table 1–1. Responses to the letter survey were very limited but generally reflected a consensus of water quality specialists representing several agencies.

#### 1.1.2.3 Water Quality Work Group Scoping

As indicated above, the water quality problems in the Columbia River Basin are quite diverse. The system operation review explores a range of strategies based on the manipulation of river flows and the water surface elevation in project reservoirs. Dissolved gas saturation, water temperature, and turbidity issues can be addressed, at least partially, by these strategies. Other water quality problems are either remotely or not at all related to hydropower operations. Information required to make the connection between system operations and water quality in those cases may also be unavailable.

Water conditions required by various river users differ and sometimes conflict. Meeting the needs of anadromous fish, for instance, can be at the expense of resident fish, recreation, navigation, flood control, and power. The design of an alternative satisfying all these requirements is impossible. Instead of attempting to create a "water quality alternative" the group decided to assess the water quality implications of alternatives designed to meet other objectives. They also formulated reservoir operating rules for improving water quality or preventing its degradation.

## Table 1–1. Top Twenty Water Quality Parameters

< ..... river reaches ..... >

| **Reach 1 Border to Grand Coulee** | **Reach 2 G. Coulee to Snake Riv.confl** | **Reach 3 Snake R. to Bonneville** | **Reach 4 Snake R.** | **Reach 5 Yakima** | **Reach 6 Willamette River** | **Reach 7 Bonneville to Ocean** |
|---|---|---|---|---|---|---|
| 1 DIOX/FUR | DISSGAS | PESTICIDES | TEMP | TEMP | DIOX/FUR | DIOX/FUR |
| 2 DISSGAS | PESTICIDES | DISSGAS | TSS | PESTICIDES | PCB | PESTIC. |
| 3 Cd | Hg | DIOX/FUR | DISSGAS | TURB | TEMP | PCB |
| 4 Pb | TEMP | TEMP | PESTICIDES | DDT | PESTICIDES | Al |
| 5 Hg | Cd | Pb | TOTPHOSPH | TSS | Cu | TEMP |
| 6 AS | DIOX/FUR | Hg | TURB | TOTPHOSPH | Pb | DDT |
| 7 Zn | As | As | SOLPHOSPH | TKN | Hg | DISSGAS |
| 8 PCB | Pb | PCB | AMMONIA | AMMONIA | Zn | Cd |
| 9 Cu | Al | VOC | DIOX/FUR | DISSGAS | TOTCOLIFOR | Hg |
| 10 PESTICIDES | Zn | Cd | BOD | SOLPHOSPH | DDT | TSS |
| 11 Al | Cu | TURB | TKN | BOD | CHLOROPHEN | BOD |
| 12 Be | Se | Al | DDT | FECALCOLT | TSS | CHLOROP. |
| 13 Cr | TURB | Cr | TOTCOLIFOR | Hg | TURB | Cu |
| 14 Fe | Ce–137 | Se | Ph | Ph | BOD | Cr |
| 15 Ba | Ba | Cu | FECALCOL | Pb | pH | Pb |
| 16 Ni | Be | Zn | TOC | TOTCOLIFOR | TOTPHOSPH | As |
| 17 Ag | Cr | ADSORORG | Hg | Cd | Al | Zn |
| 18 TOTPHOSPH | Fe | Ba | Pb | VOC | As | VOC |
| 19 Se | Ni | Be | Cd | Cu | Ba | TOTCOLIF. |
| 20 TEMP | Ag | Fe | VOC | Zn | Be | TURB |

Notes:

(1) ranking is by order of importance, as perceived by the professional agencies surveyed. 1 is most important; 20, least important;

(2) standard chemistry symbols are used whenever applicable (See Chemistry Symbols in Part 7.0, Glossary of Terms and Acronyms). Other abbreviations/acronyms are as follows in their order of appearance in the table: DIOX/FUR= dioxin/furan, DISSGAS= dissolved gas, TOTPHOSH= total phosphorous ammonia, TEMP= water temperature, TUR= turbidity, ADSORORG = adsorbable organic, TSS = total suspended sediments, TKN= total Kjeldahl nitrogen, SOLPHOSP= soluble reactive phosphorous, BOD= biochemical oxygen demand, TOTCLIFOR – total coliform bacteria, TOC= total organic carbon, VOC= volatile organic compounds, FECALCOL= fecal coliform, CHLOROPHEN = chlorophenol.

The limited quantity, fragmentary nature, and quality of information can also be a serious handicap in describing and predicting water quality. The most critical deficiency is in data that address interactions between water quality problems and river operations. Additionally complicating the study of Columbia River Basin water quality is the large number of river systems involved. Each of these systems contains major reservoirs with unique characteristics. Analytical tools or models for addressing contaminants such as trace metals, radionuclides, and nutrients in this variety of settings need more calibration data to be reliable.

Water entering the study area from Canada and the upper Snake River basin compounds these problems. While originating outside the geographical scope of SOR analysis, the condition of these flows has a cumulative effect on water quality in the lower reaches of the river. Loss of the spring freshet and added flows during other seasons in particular were cited in many ways in which dams have changed conditions in the lower Columbia. Although not described in detail, the impacts of the entire reservoir system, both in the U.S. and Canada, on the habitat in the lower river were provided in this water quality appendix. A compilation of papers on impacts of the hydro system on the lower Columbia River can also be found in the anadromous fish technical appendix.

These limitations were also identified:

(1) only the broad, basinwide picture on the main stem Columbia/Snake Rivers was assessed, exclusive of any other tributaries;

(2) very little information is available linking contamination from point source pollutants such as pulp and paper plants and nuclear reactors to mainstem water quality;

(3) groundwater quality conditions and their relation to system operations could not be predicted;

(4) the areas downstream from Libby and Hungry Horse Dams were not modeled for water quality because of a lack of data; and

(5) daily variations of water quality parameters could not be predicted with the information provided by the hydroregulation model used in the System Operation Review.

Because of these limitations, quantitative analysis was confined to three parameters, dissolved gas saturation, water temperature, and sediments (turbidity). Other parameters which affect water quality, while important to overall environmental quality, were evaluated qualitatively. Sediment–associated nutrient and contaminant loads due to erosion were assessed quantitatively, but input data was so limited that model results had to be evaluated qualitatively. They should be reassessed during the next round of the SOR after sufficient data has been collected.

### 1.1.3 Areas of Controversy

There is disagreement about the validity and reliability of models used to analyze some water quality contaminants. Three major water quality conditions affected by system regulation ——water temperature, dissolved gas saturation, and suspended sediment —— can be modeled with reasonable accuracy. Other parameters could only be assessed qualitatively.

There are also differences of opinion about water quality in the future. They revolve around predictions about future legislation (re–authorization of the Clean Water Act) and advances in pollution control techniques and irrigation practices.

## 1.2 DEVELOPMENT PROCESS OF WATER QUALITY APPENDIX

Preparation of the Water Quality Appendix is a cooperative effort between the three lead agencies for SOR and other agencies and organizations with representatives on the water quality work group (see List of Preparers). The appendix is intended to provide an accurate picture of water quality conditions under existing conditions and those which would be produced by the implementation of a range of alternatives.

Interagency staff members performed the multitude of analyses needed to evaluate the relative merits of the proposed alternatives. They were guided by suggestions and assessments by the general membership of the work group and other interested parties. Outside contractors were also retained to assist with specific analysis and report writing.

Water quality work group members have demonstrated knowledge and experience that encompassed many aspects of water quality. They started meeting about once a month since mid–1991, and undertook numerous research and writing assignments.

### 1.2.1 Development of the Work Group

Interagency staff members were nominated by agency heads on the basis of current responsibilities in the field of water quality. Other work group members were invited after referrals disclosed interest in and knowledge about water quality. This included people associated with universities, private citizen groups, Indian tribes, and federal and state agencies. Representatives of the following agencies and groups were regular and continuing participants:

- U.S. Corps of Engineers
- U.S. Bureau of Reclamation
- Bonneville Power Administration
- U.S. Geological Survey
- U.S. Environmental Protection Agency
- National Marine Fisheries Services
- U.S. Soil Conservation Service
- Lake Roosevelt Water Quality Council
- Citizen For a Clean Columbia
- Oregon Department of Environmental Quality

Representatives from Portland State University (Civil Engineering Department), Environment Canada, Washington Department of Community Development, the Corps of Engineer's Hydrologic Engineering Center and Waterways Experiment Station, and U.S. Fish and Wildlife Service were occasional participants.

Many other state agencies and private citizens have asked to be included on the mailing list for minutes of meetings and other documents. This includes Oregon, Idaho, and Montana water quality specialists; coordinators of the Lower Columbia River Bi–State Program; and Corps of Engineers research institutions (Hydrologic Engineering Center, Davis, CA and Waterways Experiment Station, Vicksburg, MS).

### 1.2.2 Coordination with Other Work Groups

Since water is central to virtually every other resource involved in the SOR, close coordination with other work groups was essential. The water quality group routinely coordinated its activities with the anadromous fish, resident fish, irrigation, navigation, cultural resources, recreation, hydropower, and wildlife work groups. Input for and results from water quality models had to be available and consistent with information sought and generated by these other work groups.

Examples of information exchanges included impacts on water quality from irrigation return flows, data regarding ship movement, effects of water temperature, dissolved gas saturation, and turbidity on anadromous and resident fish, effects of sediment build–up and river bank erosion on cultural sites, and information about water transparency and purity for recreation.

A joint meeting was held with the anadromous and resident fish work groups to determine the nature and extent of their water quality objectives. Meetings with the anadromous fish group were also held to coordinate methodologies for predicting dissolved gas saturation.

Regulated flow data for each SOR alternative were obtained from the river simulation work group and the economics group provided methods for assessing water quality benefits. There was a continuous exchange of information about the content, format, and style of this document with National Environmental Policy Act guidance group. Sustained liaison was maintained between project managers and work groups on budgeting, scheduling, and overall coordination.

## 1.3 SCREENING ANALYSIS

More than 90 alternatives were initially developed by SOR work groups to address a full range of system operation possibilities. Some were extreme, providing for a single interest at the expense of other considerations. Others attempted to achieve some compromises to accommodate a number of resources.

Screening analysis was a rough, first–cut assessment to eliminate extreme alternatives from further consideration. Screening permits the grouping similar alternatives for full–scale analysis.

## 1.4 SELECTION OF ALTERNATIVES

Initial screening was useful in establishing how the system would respond to operations optimizing conditions for single resources. It helped identify alternatives that could solve specific problems, but would also negatively affect too many other water users.

Public comment on the results of screening analysis was then solicited at a series of meetings. The most promising alternatives in terms of predicted impacts on and potential acceptance by all water users were retained for a more complete, full–scale analysis. Many were combined with other variations to form alternatives with broader but generally compatible goals and objectives.

Full–scale analysis was a more detailed evaluation using state–of–the–art modeling to rate the relative merits of the various alternatives and rank them in terms of effects on water quality. The performance of each alternative was assessed both quantitatively and qualitatively based on predicted water temperature, dissolved gas saturation, and, when applicable, sediment transport.

The results of the water quality evaluation were combined with the results of other SOR other work groups and composite ratings were calculated for use in the selection of the recommended alternative(s).

## 1.5 FULL–SCALE ANALYSIS

To comply with the National Environmental Policy Act, full–scale assessment of all environmental effects associated with the implementation of each alternative was required. This included a "systematic, interdisciplinary approach which will ensure the integrated use of the natural and social sciences and the environmental design arts in planning and in decision–making". Environmental indices were developed to characterize the relative significance of the predicted impacts.

Three different mathematical models were used to predict how each strategy would affect water temperature, dissolved gas saturation, sediment transport, and other water quality parameters. This process is described in detail in Chapters 3 and 4 of this document.

# CHAPTER 2

# WATER QUALITY IN THE COLUMBIA RIVER BASIN TODAY

## 2.1 INTRODUCTION

The Columbia River watershed encompasses a 259,000–square–mile area shared by two nations and six States (Figure 2–1). The river begins in British Columbia, Canada and flows through the states of Washington, Idaho, and Oregon to the Pacific Ocean. Its major tributaries are the Kootenay, Pend Oreille, Spokane, Snake, Yakima, Deschutes, and Willamette.

Other states and provinces located in the watershed are Alberta, Canada, Wyoming and Montana. There are several small and large rivers that enter into these tributaries. Each state has its own water quality standards, and management and monitoring programs. The waterways within the watershed are also regulated by several federal, state, tribal, and local agencies, each having responsibilities for water rights, allocation, flows, and operation of the system.

Compared with other regions in the nation, water in the Columbia River Basin is still relatively clean. Concern about the permanence of this advantage, however, has been growing. Population growth, mining, logging, agriculture, and industry have created and are continuing to create significant problems. Columbia River dams have been associated with the production or exacerbation of chemical, physical, and thermal pollution.

## 2.2 ACTIVITIES AFFECTING WATER QUALITY

### Dams and Hydropower

The major purpose of dam construction on the Columbia was to prevent flooding and produce electricity. In most cases, irrigation, navigation, and recreation were secondary benefits. Dams impound water and can sharply reduce river velocity. As a result, sediment will either settle on the bottom of the reservoir or remain suspended in the reservoir's water column, potentially affecting turbidity and concentrations of contaminants in the reservoir or downstream. Sediment transport downstream of dams is affected because natural river processes replace the suspended sediment that was removed by the upstream dams.

Water released over spillways and heating (solar and geological) can also increase gas levels which can cause gas bubble disease in fish. Gas bubble disease can kill fish and may cause behavioral disorders. Fish tolerance to elevated gas pressure varies with fish species, life history stage, water temperature, hardness, depth, and length of exposure.

Water temperature is also affected by dams. After a stream is impounded, more of its water surface area becomes exposed to solar radiation, precipitations, evaporation, and wind effects. At the microclimatic level and depending on local conditions and mesoscale meteorological elements, new lakes may have some influence over weather and climate. Creation of large deep reservoirs normally causes stratification or layers of water with different physical and chemical properties. Dams can radically change the temperature and gas pressure of the water released downstream, impacting the aquatic ecosystem.

Flow releases from reservoirs are regulated by a series of operating rule curves designed to ensure that the dams perform their authorized functions. Actual releases, however, depend on run–off conditions. Generally, more water is stored and released during a high flow year than during a low flow year, resulting in different impacts on water quality in reservoirs and areas downstream from the dams. More flows also means higher potential for spill. As most of the Columbia and Snake River is now a series of stair–step impoundments (see Figure 2–2), the water moving downstream does not circulate sufficiently to rid itself of gas entrainment at the upstream dams. As a result, dissolved gas supersaturation created by spill at one dam will often stay at or above that initial saturation level as the water flows toward the ocean.

Dam operational measures could result in downstream scouring, increased gas supersaturation, decreased dissolved oxygen in deeper water, increased turbidity, and resuspension of contaminated fine sediments. Upstream impacts may include decreased water volumes and flows, increased temperatures, decreased dissolved oxygen concentrations, increased pollutant concentrations, and altered mixing of outfall discharges. These effects could result in violations of water quality standards.

**Fisheries**

Development of the dams and hydroelectric projects on the Columbia and Snake rivers has altered natural flows in those streams. Part of the natural spring run–off which juvenile salmon and steelhead relied on to make their outmigration to the ocean is now stored in reservoirs for use in drier parts of the year. To speed up fish travel time, the Northwest Power Planning Council established a water budget, a volume of water set aside for fish. It is released from upriver storage dams during the spring run (April 15 – June 15) to create an artificial freshet.

The original water budget amounted to a total of 4.03 million acre–feet –– 2.39 million acre–feet at Priest Rapids Dam and 1.64 million acre–feet at Lower Granite Dam. Since its inception in late 1982, the water budget has been increased several times. In 1993, the water budget provided by Dworshak Reservoir for the Lower Snake River was about 1.1 million acre–feet, and the water budget provided by the upper Columbia River reservoirs was about 6.45 million acre–feet. Release of this water augments flows in the main stem Columbia and Snake Rivers, and generally benefits water quality as well.

To reduce fish mortality at dams located along the juvenile migration routes, the Council's original Fish and Wildlife Program also called for an interim measure known as "spill for–fish–passage". Accordingly, sufficient water was spilled to keep the fish away from the turbines and to guarantee at least a 90 percent fish passage survival rate at each dam. Other performance criteria such as Fish Passage Efficiency (percent of fish passing a dam through a route other than the turbines) have also been used.

In 1989, a Fish Spill memorandum of agreement was signed between Bonneville Power Administration and several state, federal, and Indian Tribes fishery agencies specifying more finite spill percentages of the outflows at Lower Monumental, Ice Harbor, John Day and The Dalles Dams. These percentages, expressed in percent of daily average project outflows, were respectively 70, 25, 0, and 10 percent for the spring (April–May); and 70, 25, 20, and 5 percent for the summer (June–August). At Bonneville Dam, the Corps of Engineers spilled nightly 53 percent of the project outflow in the spring, and 41.5 percent of the project outflow in the summer.

Although spill for–fish–passage has been discontinued at Lower Monumental Dam, following completion of permanent fish bypass facilities at that project in 1992, it is likely to continue at other projects for some time. In the mid–Columbia River reach between Wells and Priest Rapids Dams, the mid–Columbia Public Utility District (PUD) dams continue spilling the amount required in their FERC licenses during June–August. This varies from about 2 to 20 percent of daily average project outflow.

**Agriculture**

Approximately seven million acres of farmlands were irrigated in the Columbia River Basin in 1990 (Columbia Basin Project Expansion Draft EIS, USBR). This included 3.3 million acres in Idaho, 0.4 in Montana, 1.9 in Washington, and 1.3 in Oregon. These figures were expected to remain fairly steady over the next 30 years. Water diverted for irrigation evaporates or transpires, seeps into the ground, or runs off the end of fields, eventually returning to the river or tributaries as a point or non–point source of pollution.

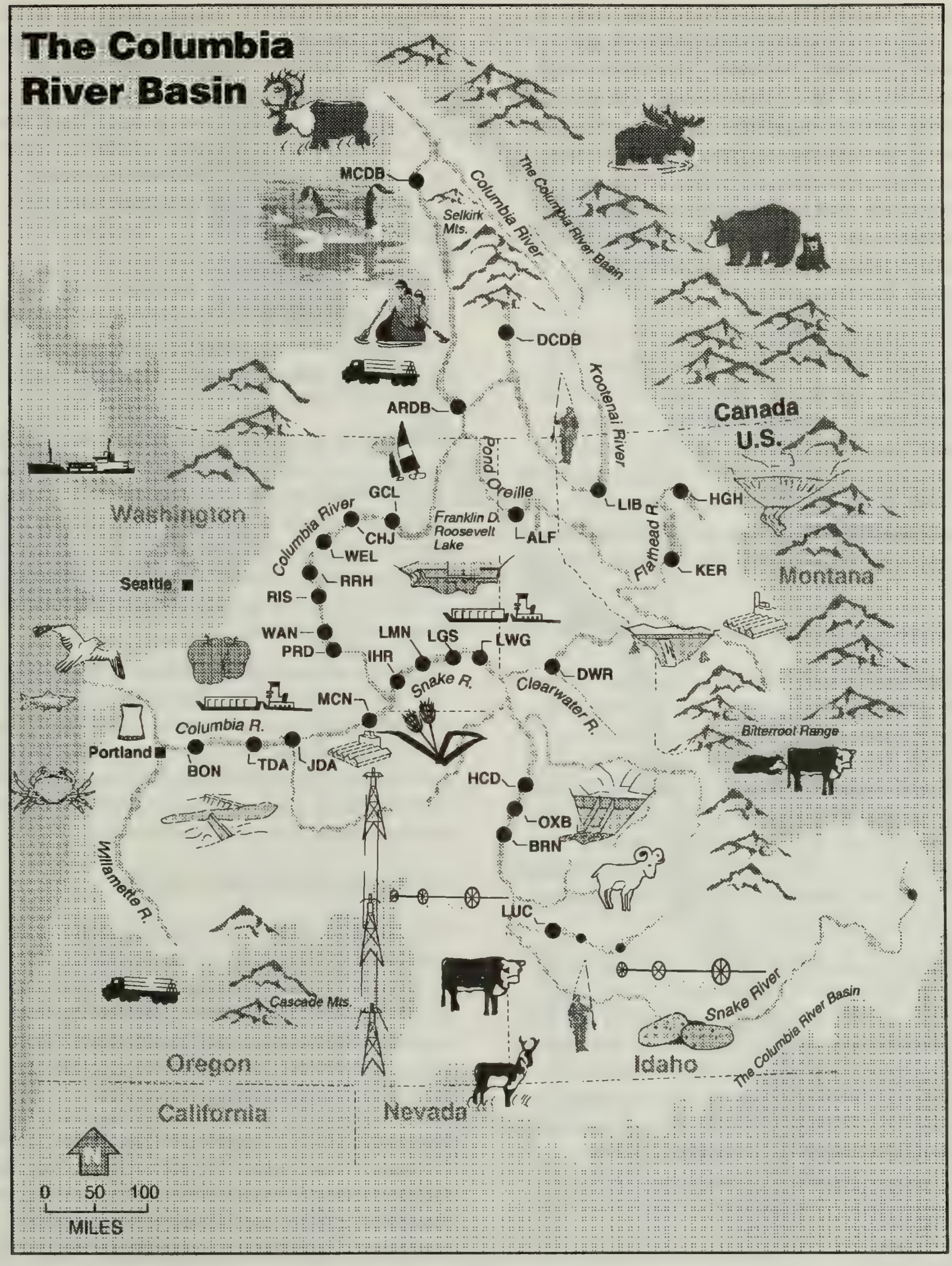


**Figure 2–1. The Columbia River Basin**

Irrigation return flows may elevate water temperatures, increase suspended sediments, and contain fertilizers, pesticides, herbicides, and natural salts leached from the soil. Irrigation return flows are frequently warm and polluted and can enter rivers, lakes, and groundwater supplies. High concentrations of phosphorous and nitrogen may cause small lakes to choke with aquatic weeds and algae. Dead plants sink to the bottom where they are broken down by bacteria, a biochemical process which consumes dissolved oxygen.

Livestock grazing adjacent to rivers and streams can have a significant impact on stream water quality. Poor grazing management practices destroy riparian habitat adjacent to streams and other vegetation necessary to prevent erosion. Heavily grazed watersheds usually exhibit less holding capacity; higher than normal spring run–off causes increased velocities and sedimentation. Streams that would normally run year–round can become dry or intermittent as a result.

### Navigation and Transportation

Transportation on the Columbia River has been vital to the economy of the area. Wheat growers and many industries along the river depend on it to transport their products to market. Many large vessels and barges travel up and down the river daily requiring channels deep enough for them to navigate. Most of this traffic is between Portland, Oregon and Lewiston, Idaho where sufficient navigation draft has been maintained and dams are equipped with adequate navigation locks.

Dredging to maintain navigation channels, mostly between the mouth of the Columbia River and Portland, affects the hydrology of the river channel and disturbs the channel bottom. It can also increase the velocity of the current and the movement of suspended sediments, which can scour the bottom and shoreline. Disruption of the river channel can be detrimental to the riverine ecological balance. Dredging also disturbs sediments containing toxic substances that can be harmful to plants and animals.

The possibility of accidental spills from barges, other vessels, and trains running parallel to the river exists. Most are small spills of gasoline, diesel, or oil but the cumulative effect on the river's ecology may be significant. Larger, more serious spills require notification of the proper authorities and immediate clean–up measures. Because of the size and velocity of the river, containment is very difficult. Depending on the type of material spilled and the location, sections of the river could be affected for many years.

### Mining

Mining has occurred extensively in Columbia River Basin. It has diminished significantly in recent years because of economic conditions and new environmental regulations.

The environmental effects of mining can be both long and short term. Erosion from soil disturbance creates sedimentation in rivers and streams. Some mining operations divert water from streams for various purposes; return flows can be polluted with toxins and heavy metals. Separation of minerals sometimes requires the use of chemicals and metals harmful to aquatic systems.

Mining in streams can also disturb stream bottoms and shoreline vegetation. Mines that have been closed for years can continue to affect streams when precipitation passes through mine tailings or cavities in the tailings created during mine operation. A restored water table can cause contaminated groundwater to resurge into nearby streams.

### Timber and Wood Product Industry

The timber industry, extremely important to the economy of this region, has been under close scrutiny in recent years because of impacts to watersheds and fish and wildlife habitat. The wood product industry has also been criticized because of contaminated by–products and chemicals produced and discharged into the rivers and streams.

Numerous pulp and paper mills are located in the Columbia River Basin. The standard process often requires chlorine bleach. By–products of this process include dioxin and furans which are known carcinogens. Dioxin and furans have a long half life, which means they can remain in a riverine environment for several years.

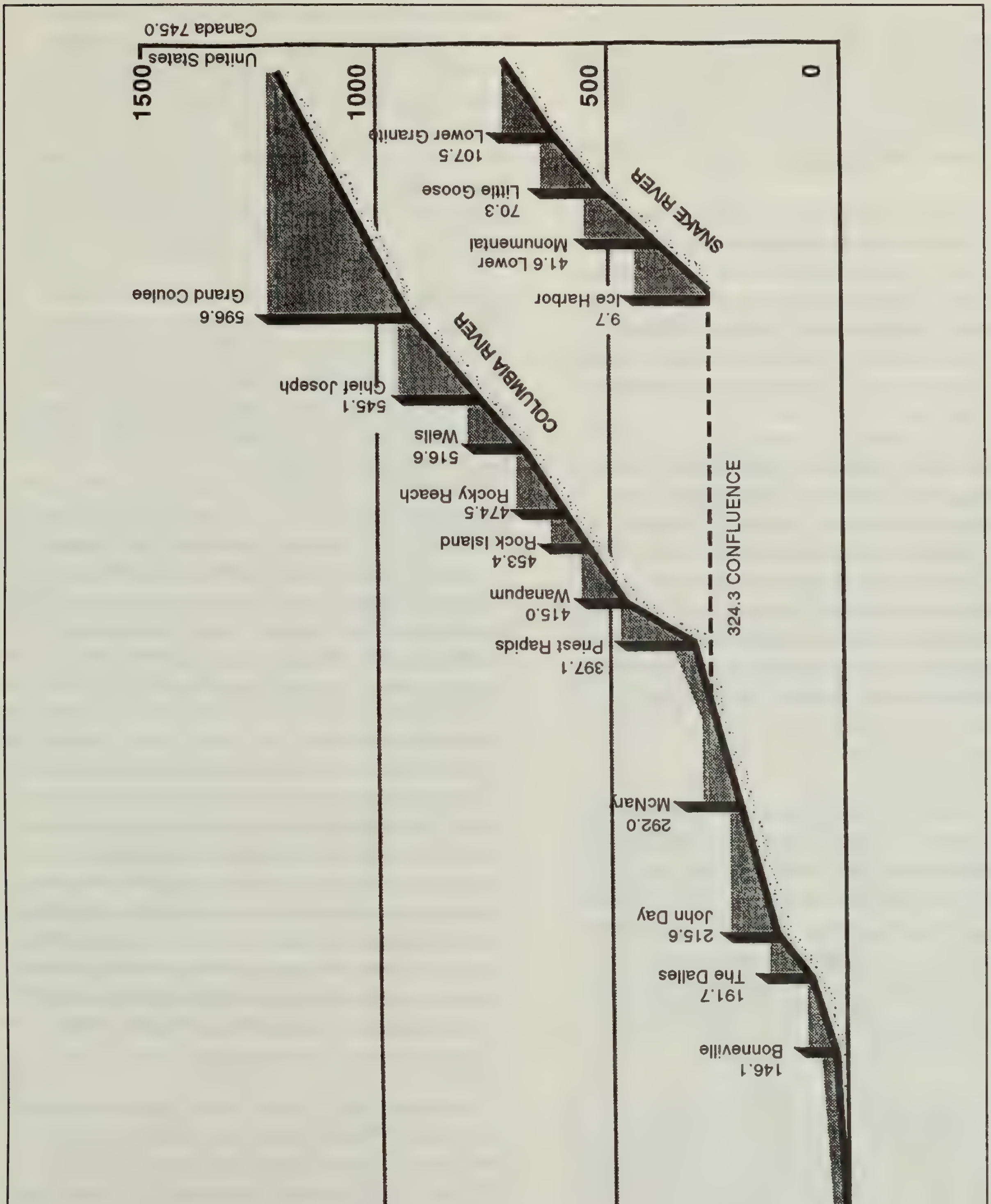


**Figure 2–2. US Columbia River and Lower Snake River Dams (Showing River Miles)**

New technology minimizes the emission of dioxin and furans, and new laws and regulation are requiring pulp mills to use it. Other by–products harmful to the environment are still being discharged into the river. These include other organic chlorides, acids and bases, fibre and resins.

Several harmful chemicals are used to produce plywood and pressed wood. If these chemicals are not properly treated and disposed of they can pollute the river. There are a few examples of streams and reservoirs being damaged by dumping from pulpmills and other factories. Lower summer water levels, by reducing the assimilative capacity of the streams, may make matters even worse.

Harm to watersheds from logging and associated road construction in the Northwest is well documented. Logging impacts streams and rivers by increasing erosion, temperature, and altering stream morphology. New logging techniques and recognition of the detrimental effects of past logging practices are reducing these effects to some extent. Nevertheless, logging is still a major factor in the degradation of water quality in the Columbia River Basin.

### Urban Development

Urban development has increased over the past 50 years, spreading over thousands of acres of wetlands and affecting the natural geology. Wetlands are not only valuable habitat for a variety of fish and wildlife, but also act as natural sinks collecting, filtering and biodegrading organic detritus. Each town, city, home, and business located in the basin may affect the river's water quality depending on its location and type of treatment systems.

**Sewage Treatment plants** – Before the Federal Water Pollution Control Act (FWPCA) Amendments of 1972, the wastes discharged into the river by cities and towns were not monitored as closely as they are today. Although the majority of the cities and towns treated their discharged wastes, some organic compounds and inorganic chemicals were still entering streams. After Congress passed the Clean Water Act, section 303 required the states to develop instream water quality standards, and section 404 required National Pollutant Discharge Elimination System (NPDES) permits and a monitoring program for each entity that discharged wastewater from a point source into navigable streams. When the FWPCA was amended in 1977, Sections 307 and 402 required pre–treatment of pollutants which pass through or interfere with municipal treatment systems and those which may contaminate sewerage sludge.

**Septic Sewage Systems** – Septic systems located adjacent or near rivers and streams can be a source of nutrient, and bacteria loading. Septic systems are normally regulated by county ordinances. It is not known how many septic systems contribute to the pollution of the river's watershed, but their cumulative effect could be significant.

**Stormwater run–off** – The Environmental Protection Agency has recently determined that stormwater run–off from industry and municipalities is a major contributor to the pollution. Regulations have been adopted that require industry and cities to minimize and, if necessary, treat stormwater before it enters rivers, lakes, and streams.

### Other Industries

Other industries that may affect the basin's water quality indirectly or directly are aluminum, food processing, and nuclear power. The aluminum industry is a major employer in the Pacific Northwest and requires very large amounts of electrical power. With the closure of the Trojan plant, nuclear power is a relatively small source of energy at the present time but could be more significant in the future if safety concerns can be satisfactorily addressed.

When industries are located near or adjacent to the river or its tributaries, industrial discharges can affect water quality depending on the type and level of treatment. For example, large nuclear power plants require large amounts of water for the cooling process. If this water is released into the river at higher than normal temperatures it could adversely affect the ecosystem. Accidental spills of radioactive material could also adversely affect the river's water quality.

**PCBs in Water and Sediments**

Polychlorinated Biphenyls (PCBs) are part of a group of synthetic organic chemicals known as chlorinated hydrocarbons. From 1929 to 1977, PCB–containing products were manufactured in large quantities because of their stability, and flame–retardant and heat–transfer properties. They were and still are widely used in motors, electrical equipment, electromagnets, pumps, cutting oils and some household appliances.

The properties which made PCBs attractive for use also made them an environmental and health liability. They are persistent, can concentrate their toxicity in the food chain, and are widespread, occurring everywhere in the world. PCBs accumulate at an average level of 2.3 ppm in human fatty tissue and an average of 1.2 ppm in human breast milk.

PCBS are stringently regulated under the Toxic Substances Control Act (TSCA) with strict labeling and disposal requirements. Since the TSCA's passage in 1976, the nation's industries have been phasing out existing PCBs. These efforts have concentrated on removing high level PCBs in the dielectric fluids of electrical transformers and capacitors, and in industrial machinery. Because transformers and capacitors tend to fail catastrophically, TSCA requires soil around a high level PCB spill to be removed for disposal as a hazardous waste. Many pieces of totally enclosed PCB–containing equipment such as household or industrial/commercial appliances still remain in service. Others have been buried in landfills. EPA's Virtual Removal program is intended to remove PCBs completely from service before they can escape to the environment. In the long term, this effort should prove less costly than treatment of contaminated areas that would result from future leakage of this equipment.

During the last decade, the Corps of Engineers conducted an aggressive PCB removal and replacement program to eliminate the risk of PCB releases at its dams on the Columbia and Snake Rivers. All of the transformers at these dams are now classified and labeled as non–PCB, as are the oil circuit breakers. For example, at Bonneville Dam, the last 12 oil circuit breaker bushings which might contain small amounts of PCBs are scheduled to be replaced by the end of 1995. There are no PCB capacitors in use at the dam. No PCB or PCB–contaminated equipment is in service at McNary Dam, nor at any of the Corps' Snake River dams.

Due to historical practices associated with their use, PCBs may have leaked or spilled into the soil or been transported into bodies of water. They can be expected in Columbia mainstem reservoirs because of contributions from tributaries and discharges from industrial sources, wastewater treatment plants and landfill leachates.

Monitoring of sediment, fish tissues and water during the Oregon–Washington Bi–State Study detected PCBs in several locations below cities in the study area, in rivers, ports and in the Columbia River estuary. Other monitoring programs, such as those associated with Lake Roosevelt and the Columbia River Integrated Environmental Monitoring Program (CRIEMP), detected PCBs and other persistent industrial pollutants in the bottom sediment of the Columbia on both sides of the interstate border. Additional monitoring is needed throughout the basin to delineate hot spots and conduct risk assessments. These sediment quality data should be entered into the National Inventory of Contaminated Sediment Sites and Sources, managed by the EPA Office of Science and Technology. Associated fish contamination data should be entered into the same national data base.

Under extreme river operations scenarios, there may be a risk of resuspension of sediment laden with PCBs, metals, pesticides if contaminated areas are disturbed. Most of the anticipated effects will fall within a range associated with current operations. However, the timing and duration of these effects may vary or be displaced seasonally due to changes in spill programs. The general lack of data on location and distribution of toxic substances such as PCBs does not allow accurate prediction of health effects or changes to chemical quality of the water. This must be remedied through a long term collaborative monitoring effort for these substances. During the May 1992 drawdown test in Lower Granite pool, samples taken contained no PCBs.

## 2.3 RESPONSIBLE AGENCIES AND GROUPS

### 2.3.1 Federal, State, and Local Agencies

The major federal agencies authorized to operate the dams and control the river for power and flood control are the U.S. Army Corps of Engineers and the Bureau of Reclamation. The Bonneville Power Administration works closely with these two agencies, with authorization to market and distribute the power generate at federal Columbia River Basin dams.

Other federal agencies responsible for land use activities and recreation on the river are the National Park Service (NPS), Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (USFWS), and U.S. Forest Service (USFS). The federal agency responsible for water quality within the river basin is the U.S. Environmental Protection Agency (EPA). Agency responsibilities often overlap, requiring close coordination to protect the resource.

There are several state, county, tribal, and local government agencies also responsible for the various activities on the river. The responsibility for water quality and associated land use practices, in most cases, flows from Federal to State, and State to county and local government.

Numerous efforts in the Basin include monitoring activities. These activities cover an array from water column chemistry to riparian condition to watershed land uses to fish surveys and even to some macro–invertebrate surveys. Major monitoring objectives of water quality monitoring in EPA and State water quality programs are :

- **comprehensive status and trends**
  problem identification/trends
  emerging problem characterization
- **watershed assessments**
  urveillance/screening
  regulatory decision making
  water quality–based control development
  investigation of cause–effect relationships
- **program effectiveness**
  compliance
  public information and education
  evaluation of measures and projects.

An example of comprehensive multi–agency basin-wide monitoring directly related to the operation of the Columbia River system is the Columbia and Snake Rivers Dissolved Gas Monitoring Program. This Program, in operation since the mid–1970s at Corps projects, was expanded to cover other non–Corps dams in 1984. The network currently consists of 33 automated stations located in the forebay and tailwater areas of most mainstem dams, with satellite linkage between the various measurement sites and the ground receive stations in Boise, Idaho and Portland, Oregon (Figure 2–3). Its objective is two–fold: 1) to provide the water quality data needed to adjust spill at Columbia and Snake River mainstem dams; and 2) to check for compliance with existing state water quality standards.

Uncompensated total dissolved gas (TDG) saturation, which can cause lethal gas bubble disease in fish, is the primary water quality parameter monitored by agencies operating the Columbia River dams. Water temperature is also monitored because of its critical impact on fish and aquatic life. To relate these two parameters to project operations, data on the spill itself are also routinely collected. As such, the dissolved gas monitoring program is very much an integral part of water management.

Daily monitoring of dissolved gas saturation and water temperature is carried out during the juvenile fish migration season, April through October. Major participants include the Corps of Engineers (COE), U.S. Bureau of Reclamation (USBR) and the mid–Columbia County PUDs (Chelan, Douglas and Grant). During high run–off years, emphasis is usually on TDG saturation and spill. During low run–off years, the emphasis shifts to water temperature and powerhouse releases. The TDG data are maintained in the Corps North Pacific Division's Water Quality Data Base and are widely disseminated to project owners and other agencies through the Columbia River Operational HydroMet System (CROHMS).

### 2.3.2 Citizen Involvement Organizations and Programs

In addition to government agencies, many citizen involvement groups are active in promoting, managing or implementing water quality programs in the Columbia Basin. Some of these groups are indicated below, a list that is not exhaustive.

**Washington**

State–wide organizations include Citizen Lake Monitoring Project (Washington Department of Ecology), Washington State University Cooperative Extension Water Quality program, and the Washington State Lake Protection Association. More localized organizations and programs are listed below:

Adopt a Stream Foundation: A citizen training program under which people "adopt" a watershed. Participants are trained to assess the watershed, monitor the conditions, and take local action based on their findings.

Citizens for Clean Columbia: Based in Colville, an advocacy organization involved in the Lake Roosevelt Forum. Provides education programs.

Clark County Water Resources Council: Advocacy group dedicated to encouraging people to monitor, improve and advocate for water quality resources. Activities include streamwalk, stream stewardship, lake monitoring, and storm–drain monitoring.

Clark County Cooperative Extension: Stream watch program under which trained volunteers assist in educational and organization programs related to the dynamics of stream water quality.

Environmental Information Center: Provides information to citizen groups and students. Also sponsors streamwalks and other monitoring activities. A program of the Clark County Public Utilities.

Lake Roosevelt: Lake Roosevelt Water Quality Council will be developing a citizen monitoring program.

Northwest Rivers Council: An organization designed to protect the natural values of rivers in Washington, Oregon, Idaho and Montana. Has been instrumental in establishing the Oregon Rivers Council and Idaho Rivers United. Main focus is water quantity. Major activities include sponsorship of an annual conference advocacy, citizen involvement in policy groups and provision of technical information.

**Idaho**

Idaho Water Resources Research Institute manages the streamwalk program for Idaho. Also, is involved in citizen education and training programs which include Streamkeeper and Project WET.

Idaho Department of Fish and Game manages a public involvement program designed to protect and restore fish habitat. Also very involved in water quality education.

Idaho Rivers United: An advocacy organization which also has a citizen monitoring program. Sponsors student monitoring program.

Kootenai Environmental Alliance: Located in Northern Idaho, organization has advocacy role as well as monitoring activities. Interested in policy development within the community.

North Idaho Lakes Coalition: A coalition of lake associations. Major activities include advocacy and monitoring the water quality in northern Idaho lakes.

Northwest Water Watch: Patterned after the WSU Cooperative Extension Bay Watches Program, trains citizens and teachers in all aspects of water ecology. Trained volunteers volunteer 50 hours to work on a water related environmental issue.

Sawtooth Workshop: Trains the public, teachers and agency staff how to gather and use environmental information. Course is designed to empower participants to understand issues and take action.

Students on the Snake: A student monitoring program which sponsors five high school programs along the Snake River from Lewiston down.

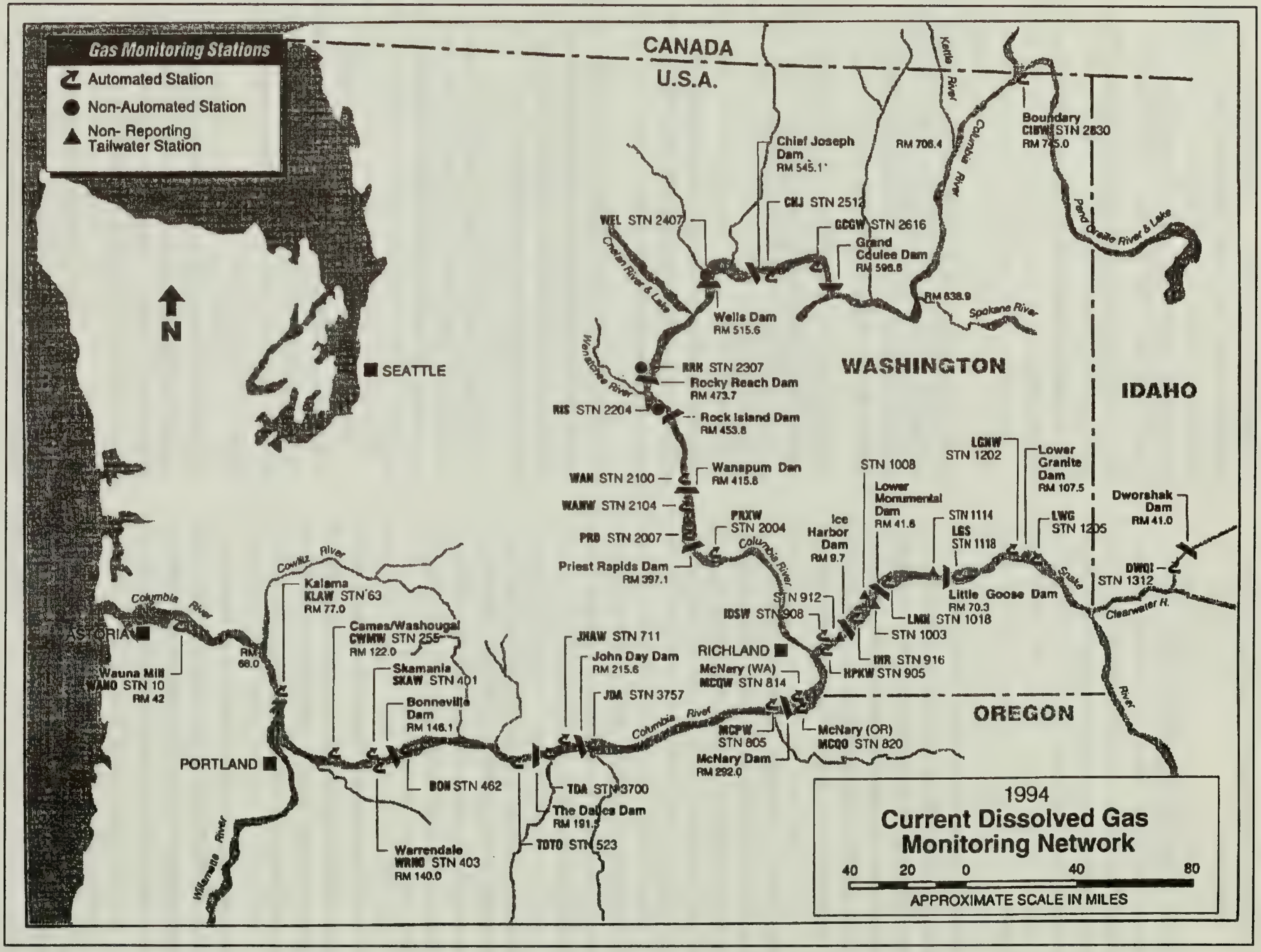


Figure 2–3. 1994 – Location of Dissolved Gas Monitoring Stations

**Oregon**

Citizen Lake Monitoring: A state sponsored program which is managed by Portland State University. Involves and trains citizens in lake monitoring.

Governors Watershed Enhancement Board: A statewide grant program which provides funding to citizen groups and others to improve or protect watersheds.

River Network: A national organization, based in Portland, which provides assistance to citizens concerned about rivers. Has a data base of information on technical assistance, a newsletter, and documentation of successful restoration projects.

FAUNA (Friends and Advocates of Urban Natural Areas): An umbrella organization to provide assistance and support to local citizen groups in the greater Portland area. Sponsors forums and conferences to train and inform citizens.

Metropolitan Greenspaces Program: Provides a regional approach in protecting natural resources in the four county area surrounding Portland area. Created the greenway corridors for animals, plants and people.

NW Environmental Advocates: An advocacy organization based in Portland. Provides boat rides to educate concerned citizens about the Columbia and Willamette. Recently published two maps, under their River Watch program, entitled: Toxic Waters, and Columbia River−−Troubled Waters.

Oregon Rivers Council: An advocacy organization working to affect national policy on the protection and restoration of rivers. Involved with other northwest states on hydro intervention issues.

Urban Streams Council: A new organization consisting of FAUNS, Greenspaces, and the multitude of groups monitoring local streams and rivers. Focus is on the Tualatin and Willamette Rivers.

Saturday Academy: An educational program that includes a National Science Foundation program to monitor the Tualatin River.

## 2.4 LAW, REGULATIONS, AND PROGRAMS RELATED TO WATER QUALITY

### Clean Water Act (CWA)

The Federal Water Pollution Control Act, better known as the Clean Water Act (CWA), is rooted in older water pollution control legislation such as the Refuse Act (1899) and the Water Pollution Control Act (1948). Its objective is "to restore and maintain the chemical, physical and biological integrity of the Nation's waters" and two goals were specified. The first is to attain a level of water quality which "provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water." The second is to minimize the discharge of pollutants into navigable waters.

**CWA Water Quality Standards.** The 1972 amendments (Section 303c) require the states to establish water quality standards for all water protected by the CWA. Renewable every three years, these standards identify the uses of each water body and water quality criteria which must be met to protect the designated (beneficial) use or uses. Section 305b imposes reporting requirements. Each state must submit biennial reports to the EPA assessing the extent to which its waters support beneficial uses, identifying point and non−point sources of pollution, and recommending actions to improve water quality.

**CWA Non−point Source Management Plans.** The CWA mandates several broad water quality planning programs to reduce the pollution of surface waters. Section 319 addresses pollution from diffuse sources such as agriculture (excluding irrigation return flows), mining, forest practices, construction, urban run−off, ground water seepage, and hydrologic modifications (such as dams and reservoirs).

Each state prepares a non−point management plan for submittal to the EPA. It includes information similar to that in the 305b water quality report but is delves more deeply into non−point source issues.

Non−point sources of pollution are generally addressed with Best Management Practices (BMPs). These are physical, structural, or managerial practices that prevent or reduce surface and ground water pollution. Examples of water quality BMPs are: bio–filtration strips, swales, stream fencing, detention and infiltration techniques, oil/water separators, and waste abatement programs. Monitoring is conducted by a variety of agencies to assess the implementation and effectiveness of these management practices.

**CWA Point Source Discharge Permits.** The discharge of pollutants from point sources into waters of the U.S. without a permit is prohibited by the CWA. Points sources are usually municipal and industrial wastewaters, non–contact cooling waters, storm waters discharged into water from outfall pipes or ditches, or combined sewer overflows.

Under Section 402 of the CWA, National Pollutant Discharge Elimination System (NPDES) permits are issued by either the EPA or states to which it has delegated the authority. Many states also issue permits for waste discharges not covered by the NPDES program.

Discharge permits specify effluent limitations which must be monitored and the types of data which must be reported. Instream as well as wastewater or storm water monitoring may be required. There are approximately 1,500 NPDES permits in the Idaho, Oregon, and Washington portions of the Columbia Basin.

Dredged or fill materials discharged into water are regulated by Section 404 of the CWA. Discharges now also include those incidental to excavation activities. Most permits for this activity are issued by the U.S Army Corps of Engineers but the EPA plays an active role in evaluating these impacts and may inspect 404 permits in emergency situations. Applicants for 404 permits must also provide certification from the appropriate State agencies that the project will not violate State water quality standards.

**CWA Oil Spill Prevention.** The CWA (Sections 311 and 308) controls the discharge of oil into or upon waters of the U.S., adjoining shorelines or contiguous zones. Certain facilities must have Spill Prevention Control and Countermeasure (SPCC) plans if a spill could enter waters of the U.S. in harmful quantities. Both the CWA and the Oil Pollution Act of 1990 use the same implementing regulations.

**Safe Drinking Water Act**

This legislation protects public water supplies including groundwater aquifers which draw from surface waters.

**National Environmental Policy Act of 1970 (NEPA)**

This legislation requires the Federal government to undertake activities in a manner which protects the environment. When "significant" environmental effects can be expected to be produced by an activity, an environmental impact statement (EIS) must be prepared. The definition of "significant" is carefully defined. NEPA is intended to be used as a decision–making tool by Federal agencies.

Alternatives for achieving the proposed action are developed in the environmental impact statement and the effects of implementing each alternative are assessed. A detailed description of National Environmental Policy Act requirements is given in the environmental impact statement for Columbia River System Operations.

**Rivers and Harbors Act of 1899**

This legislation focuses exclusively on navigable waters. Section 9 regulates the construction of bridges, causeways, dams or dikes. Section 10 addresses the obstruction of navigable waters by wharves, piers, excavations and fills. The U.S Army Corps of Engineers issues most authorizations, many of which are nationwide general permits. Section 10 permits that involve discharge (intended or incidental) must be certified under Section 401 of the CWA by the appropriate State agencies.

The U.S. Coast Guard, part of the Department of Transportation, is responsible for some permits under the Rivers and Harbors Act. Bridges over navigable waters are an example of Coast Guard permit.

**Coastal Zone Management Act (CZMA)**

This statute created a voluntary program to protect coastal resources, including the Great Lakes. To receive Federal funding, states must develop programs for regulating land and water uses associated with coastal development. These enforceable policies must also include measures for resolving conflicts among competing uses. Both Oregon and Washington have Federally approved Coastal Zone Management Programs. The Act was amended and re–authorized in 1990. Water pollution control programs and a requirement to address non–point source pollution affecting coastal water quality were incorporated.

**Executive Order 11988 (Flood Plain Management)**

The purpose of this directive is to avoid, where practicable alternatives exist, the short and long term hazards associated with floodplain development on human health and safety, and environmental impacts to fish and wildlife and their habitat.

**Federal Water Project Recreation Act**

The Policy of this act states that Federal agencies in planning navigation, flood control, reclamation, hydroelectric, or multipurpose water resource projects, must consider the potential outdoor recreational opportunities and fish and wildlife enhancement that the projects might afford.

**Executive Order 11990 (Protection of Wetlands, 1977)**

Agencies, in carrying out their land management responsibilities, are to take action which will minimize the destruction, loss, or degradation of wetlands, and take action to preserve and enhance the natural and beneficial values of wetlands.

**Fish and Wildlife Coordination Act**

The objective of this Act is to provide that wildlife conservation receive equal consideration and be coordinated with other features of water resource development plans. The Act states that whenever the waters of any stream or other body of water are proposed or authorized to be impounded, diverted, controlled or modified for any purpose by any entity, of or permitted by the federal government, the entity shall first consult with the United States Fish and Wildlife Service, and with the head of the agency exercising administration over wildlife of that state.

**Executive Order 12088 (Federal Compliance with Pollution Control Standards,1978)**

This presidential order delegates to the head of each agency the responsibility for ensuring that all necessary actions are taken for the prevention, control, and abatement of environmental pollution. Executive Order 12088 gives EPA authority to conduct reviews and inspections for the purpose of monitoring federal facility compliance with pollution control standards. Also, each agency shall submit a semi–annual plan to the Office of Management and Budget for the control of environmental pollution. The plan shall indicate methods of improvement in the design, construction, management, operation, and maintenance of federal facilities, and shall include cost estimates.

## 2.5 WATER QUALITY STANDARDS

**Idaho, Oregon, Washington**

The EPA and States of Idaho, Oregon, and Washington have established surface water criteria or water quality standards applicable to the Columbia River Basin. This discussion focuses on the State standards because they are the same as or more stringent than the Federal criteria, and are legally enforceable. The codes, rules, and regulations for these state standards are voluminous, so only selected highlights of the standards are presented in this document. All three states have established a policy of antidegradation and beneficial uses for their surface waters, which precludes the discharge or introduction of any toxic or hazardous materials that result in significant deleterious effects.

Idaho's beneficial uses are domestic and agricultural water supply, cold–water and warm–water biota, salmonid spawning, primary and secondary contact recreation, and special resource water. All except warm–water biota have been designated as beneficial for the Brownlee, Oxbow, Hells Canyon, and Dworshak reservoirs, North Fork of the Clearwater River, and the Snake River downstream of Brownlee (Source: Bureau of National Affairs, Inc. (BNA), 1991).

In a four−level water quality classification system that ranges from AA (extraordinary) to C (fair), the State of Washington has classified the Columbia River from Grand Coulee Dam downstream to the Pacific Ocean and the Snake River as Class A (excellent). Beneficial uses are water supply (domestic, industrial, agricultural); stock watering; fish and shellfish rearing, spawning, and harvesting; wildlife habitat; recreation (primary contact); and commerce and navigation (BNA, 1991).

Oregon defines various portions of the Columbia and Snake rivers as beneficial for public and private domestic supply, industrial water supply, irrigation, livestock watering, anadromous fish passage, salmonid fish rearing, salmonid fish spawning, resident fish and aquatic life, wildlife and hunting, fishing, boating, water contact recreation, aesthetic quality, hydropower, and commercial navigation and transport (BNA, 1991).

A total dissolved gas standard of 110 percent saturation at ambient atmospheric pressure is the maximum level for acceptable total dissolved gas set by the three States (BNA, 1991). Each State has, however, different thermal criteria.

Idaho specifies the criteria in relation to specific use categories. The most restrictive use criterion is for salmonid spawning, with maximum water temperatures set at 55°F (13°C) with daily averages no greater than 48.2°F (9°C).

Oregon allows no water temperature increases in the Columbia River, outside of an assigned mixing zone, when the stream water temperature is at or above 68°F (20°C). When the river is 67.5°F (19.7°C) or less, the Oregon standard dictates that no more than a 0.5°F (0.28°C) increase is allowed due to a single−source discharge. No more than a 2°F (1.1°C) increase is allowed by all sources when the stream is 66°F (19°C) or less.

In Washington, no increase over 68°F (20°C) due to human activity is allowed. In addition, no increase over 0.3°C (0.54°F) is allowed from Priest Rapids Dam (river mile, RM 309) to Grand Coulee Dam (RM 595) when the stream is naturally over 68°F (20°C). In the lower Columbia River and Snake River above the Clearwater River (RM 139.3), no increase over 0.3°C (0.54°F) caused by human activity can occur from a single source, or no increases over 1.1°C (2°F) from all activities when the stream is over 68 F (20°C). In the Snake River below the Clearwater River, the 1.1°C (2°F) restriction is dropped in favor of no temperature increase exceeding $t = 34/(T+9)$°C where $t$ = change in temperature and $T$ = background temperature.

Idaho and Washington specify that turbidity shall neither exceed 5 nephelometric turbidity units (NTU) over background levels when the background level is 50 NTU or less nor have more than a 10 percent increase when background is more than 50 NTU. Oregon simply specifies the 10 percent increase criterion (BNA, 1991).

Minimum dissolved oxygen standards vary for each State. Idaho has specific criteria below existing dams. From June 15 to October 15, these criteria require at least 6.0 milligrams per liter (mg/l; 30−day mean), 4.7 mg/l (7−day mean minimum), 3.5 mg/l (instantaneous minimum), and 6 mg/l or 90 percent of saturation (whichever is greater) for slamonid spawning uses. Oregon specifies at least 90 percent of saturation for portions of the Columbia mainstem, and Washington specifies at least 8 mg/l for Class A waters (BNA, 1991).

Fecal coliform and pH standards vary among states, use classifications, and river system reaches. Typically, pH is restricted to levels between 6.5 and 8.5 pH units. Fecal coliforms must be less than 100 organisms/100 ml.

### Montana

Montana water quality regulations are similar to the other Pacific Northwest states; water quality criteria are based on beneficial uses. For major water bodies such as the Kootenai and Flathead Rivers, the classification is B−1, with a few minor exceptions. Waters classified as B−1 are suitable for drinking, culinary, and food processing purposes after conventional treatment; bathing, swimming, and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl, and furbearers; and agricultural and industrial water supply.

There are also numerical criteria associated with the B−1 classification.

- Dissolved oxygen must not be reduced below 7.0 mg/l.
- Induced pH variation must be less than 0.5 unit between pH 6.5 and 8.5, with no change outside this range, and natural pH above 7.0 must be maintained.
- The maximum turbidity increase is 5 NTU above natural background.
- For temperature, a 1°F maximum increase above naturally occurring water temperature is allowed between 32 to 66°F (0 to 18.9°C). With temperatures between 66°F (18.9°C) and 65°F (19.2°C) discharge is not allowed that will increase temperature above 67°F (19.9°C). Where natural water is 66.5°F (19.2°C) or greater, no increase greater than 0.5°F (0.3°C) is allowed. A maximum 2°F per hour decrease below naturally occurring water temperature is allowed when water is above 55°F (12.8°C), and a 2°F (1.1°C) maximum decrease below naturally occurring water temperature is allowed when the naturally occurring water temperature is between 32 to 55°F (0 to 12.8°C).
- For bacteria, when the water temperature is above 60°F (15.6°C), fecal coliforms must neither exceed 200 organisms per 100 ml nor may 10 percent of the total samples during any 30−day period exceed 400 organisms per 100 ml.
- Also, the numerical Federal water quality criteria and national primary and secondary drinking water criteria are incorporated by reference in state laws.

## 2.6 WATER QUALITY STUDIES

### 2.6.1 General Studies

Water quality studies and monitoring conducted on the Columbia River and its tributaries over the past 20 years have been generally limited to temperature, dissolved oxygen, total dissolved gas saturation, and sedimentation. Little work has been done on toxins, heavy metals, pesticides, herbicides, and nutrients. In short, work conducted in the past provides an incomplete picture of the system's water quality.

Ongoing and more recent studies conducted by the United States Geological Survey, Environment Canada, Washington State Department of Ecology, Oregon State Department of Environmental Quality, and the British Columbia Ministry of Environment have provided good scientific data, but are limited to specific locations within the watershed.

The Environmental Protection Agency and the states conduct water quality monitoring programs to establish status and trends, and to assess watersheds. Water column data routinely collected include dissolved oxygen, temperature, fecal coliform, conductivity, nutrients, turbidity, pH, and water flow. Various stations also collect more site−specific contaminants of concern. For public water systems supplying communities of year−round residents, Safe Drinking Water Act regulations require monitoring of coliform, turbidity, inorganics, organics, and radionuclides. At sites with surface water components, monitoring for potential surface water chemical, physical and biological impacts is required. Land practices, surface water, and ground water are monitored under various projects, many of which emphasize riparian areas.

The U.S. Geological Survey (USGS) has a fixed station monitoring network throughout the basin. For Idaho, stations were established cooperatively with the State and USGS. In Oregon and Washington, the State instream network sites are different than the USGS stations. Parameters monitored include dissolved oxygen, temperature, fecal coliform, conductivity, nutrients, turbidity, pH, metals, major anions and cations, suspended sediments, and water flow.

Monitoring by the U.S. Forest Service includes traditional water column chemistry, aquatic and riparian habitat parameters, and BMP (Best Management Practice) implementation and effectiveness. The type and intensity of monitoring depends on the specific National Forest and Ranger District and the particular issues of concerns. Some forests have long–term trend stations on major streams as they leave the forest. The Region 6 Stream Survey Program surveys parameters such as pool/riffle ratio, amount of woody debris, substrate characterization, and extent of riparian cover.

The U.S. Army Corps of Engineers monitors the water quality at its reservoirs. Routine parameters include flow, temperature profiles, conductivity, nutrients, turbidity, Secchi transparency, dissolved oxygen, pH, and dissolved gas. Sediment sampling is conducted in selected locations to assess sediment contaminants of concern. The Corps has begun sampling bed sediments to assess dioxin concentrations at a few reservoir locations. The Corps also conducts some biological monitoring in its reservoirs and some groundwater quality monitoring.

For its reservoirs, the U.S Bureau of Reclamation monitors temperature profiles, dissolved oxygen profiles, dissolved gas, chlorophyll a, Secchi transparency, and a range of inorganics including nutrients and metals. The Bureau also routinely monitors irrigation drain water and works with local Soil and Water Conservation Districts and Irrigation Districts to monitor effects of their activities.

Many of the Tribes in the Basin are routinely collecting water column chemistry data, primarily in conjunction with fisheries management efforts. Typical parameters include temperature, dissolved oxygen, turbidity, and conductivity.

Myriad site–specific monitoring activities are being conducted in the basin in conjunction with research, planning, regulation, and restoration efforts. A sampling of these types of efforts in Table 2–1.

**Table 2–1. Site–Specific Studies in the Columbia Basin**

| Project | Participants |
|---|---|
| Lower Columbia River Bi–State Study | WA, OR, Pulp & Paper Indust.<br>USGS, Ports |
| National Water Quality Assessment (NAWQA) | USGS |
| Middle Snake River | EPA, IDEQ |
| Lake Roosevelt Study | EPA, WA–DOE<br>Local, USGS |
| Tualatin Basin TMDL | OR–DEQ, OR–AG, ODFW,<br>USGS, OGI<br>OSU, PSU |
| S. Fork Salmon River TMDL | IDEQ, USFS |
| Columbia Basin Dioxin TMDL | EPA/states |
| National Bioaccumulation Study | EPA |
| Hanford Superfund | EPA, WA–DOE |
| Clean Lakes Projects | States |
| Irrigation Drainage Program | USDI |
| Effects of Chlorinated Compound on WA birds | USFWS |
| EIS for Channel Deepening Project | COE |

**Table 2–1. Site–Specific Studies in the Columbia Basin – CONT**

| Project | Participants |
|---|---|
| Long Term Management Study | COE/NMFS |
| Columbia River Long–Term Biological Monitoring | NMFS |
| Willamette River Basin Study | ODEQ/USGS, Industries |
| Columbia River Estuary Turbidity Maximum | LMER UW<br>Fisheries Res.Inst. |
| GIS Inventory of Wetlands in Columbia Estuary | CREST |
| Sediment Yield Location Maps, Western States | SCS |

In summary, data needed to provide a reliable prediction on the impacts of proposed system regulation on many water quality parameters are missing. A good balance of common constituents (at least for total phosphorous and nutrients) is possible, and there are good data on indicator bacteria concentrations, pH, and specific conductance (Fretwell, M.O, USGS, 1992, personal communication). Temperature data are also quite good for the sampling stations, but not good enough to fully evaluate the effects of impoundments. There is almost no information on organic contaminants and poor data on trace metals.

Many ad hoc studies have assessed water quality in short river reaches for short time periods. Other reaches have received little or no attention. There is information to answer generic questions about almost any river system but data for quantitative answers to site specific question is often unavailable. Answers to questions about the water quality effects of dams and reservoirs, pulp mills, and agriculture are examples.

### 2.6.2 Specific Water Quality Studies

#### Lower Columbia River Bi–State Water Quality Study

The 1990 Washington and Oregon Legislatures appropriated funds for an interstate study of water quality in the lower Columbia River. The funds were used to identify and study water quality problems in the Columbia River below Bonneville Dam. Additional funding was provided by the Washington and Oregon public ports, and the pulp and paper industry.

The study, a “reconnaissance survey”, is a broad–brush look at the water quality of the lower river. It was designed to answer some general questions about possible problems, and to help decide which contaminants and locations warrant further study. It was not detailed enough for human health risk assessments, nor to present a complete picture of water quality in the lower river.

#### EPA Study for Northwest Power Planning Council

In 1992 Region 10 of the Environmental Protection Agency (EPA) responded to a request from the Northwest Power Planning Council to lead an interagency study of the water quality in the Columbia River Basin. Members of the Columbia River Water Management Group’s Water Quality Committee actively participated in this effort. The first part of the study consists of a compilation of existing water quality information, determination of additional information needs, and development of a study plan for collecting additional information. The short study report is intended to be one of the many efforts to improve communication and coordination between the water quality agencies and fish restoration entities in the Columbia Basin. Better communication was found to be crucial at this time, given the Endangered Species Act listing of salmon species and the mounting concerns over the traditional water quality parameters of temperature and sediment.

**Water Budget Environmental Assessment**

In September 1982 the Northwest Power Planning Council (Council) requested the Corps of Engineers' assistance in analyzing the proposed water budget, which is part of the Council's Fish and Wildlife Program. The Program establishes a total water budget of 4.64 million acre–feet (Maf) to be divided into 3.45 Maf at Priest Rapids Dam and 1.19 Maf at Lower Granite Dam. The intent of the water budget is to provide improved transportation flows for juvenile anadromous fish during their journey downstream to the Pacific Ocean.

As a result, studies were undertaken by the Corps to identify the impacts of alternative methods of operation for the water budget, and their impacts on operation for other project purposes. The environmental assessment evaluates the nonpower impacts of the water budget at Dworshak Dam and Reservoir. Seven alternatives were considered, and impacts on the following water use considerations assessed:

- physical (water and air quality),
- biological (aquatic and terrestrial community),
- cultural (land use, recreation, aesthetics and human interest, cultural status, manmade facilities and activities),
- ecological (food web).

The Bonneville Power Administration (BPA) also prepared an environmental assessment of "Proposed Power System Changes to Implement the Water Budget", including marketing impacts. A finding of no significant impact (FONSI) was issued in January 1983 for two of the alternatives evaluated.

The nonpower environmental impacts of the water budget at the Libby project were also assessed. A FONSI for Libby was issued in July 1983. Consequently, preparation of an environmental impact assessment was not required.

An environmental investigation was conducted by a contractor for BPA in 1984 to assess water budget impacts on the operation of the Idaho Power Company's projects ––Brownlee, Oxbow, and Hells Canyon. The Hells Canyon Environmental Investigation looked at existing surface and groundwater quality in the study area, potential impacts on water quality, and additional studies required to evaluate water budget impacts.

**Lake Roosevelt Study**

Lake Roosevelt is the reservoir created by the construction of the Grand Coulee Dam on the Columbia River in 1941. It is the largest lake in Washington and the sixth largest in the United States. Despite its importance, there has been no comprehensive assessment of the Lake Roosevelt's physical, chemical, biological, and hydrological processes in the past. To fill this knowledge gap, citizen groups and responsible State and Federal agencies decided in 1992 to form the Franklin D. Roosevelt (FDR) Water Quality Council. The Council includes management, technical, and citizen's committees. Its major goals are to clean up the lake by preventing pollution from Canada and the United States, determine the impacts of past pollution, and prepare a water quality management plan.

The FDR Water Quality Council has obtained funding to conduct studies and prepare a work plan, fund citizen participation, and hire a Project Director. The work plan was finalized in March 1992 and an integrated assessment study began in July 1992. The initial focus was on evaluating existing data and sampling sediment and fish tissue for metals and toxic contaminants in the reservoir. Reservoir nutrients and watershed sources of pollution will be more thoroughly monitored in later years.

Regardless of the progress made on controlling pollutants originating in Canada, American entities are expected to continue identifying and addressing the lake's water quality problems. This includes include Washington Ecology, EPA, and groups such as the Lake Roosevelt Water Quality Forum, the Lake Roosevelt Water Quality Council, the Citizen for a Clean Columbia, and the Lake Roosevelt Coordinating Committee.

**Kootenay River Basin Water Quality Status Report**

In 1992 and 1993, a coalition of agencies involved in the Kootenay River Basin formed the Kootenay River Network (KRN). The KRN is composed of Federal, provincial, state, tribal, industrial and citizen group representatives. Approximately 90% of the land in the Basin is government–owned or managed. Several of the participating entities funded a contractor to prepare a Water Quality Status Report. The Report documents the history of pollution sources and activities affecting water quality, fish and recreation in this international watershed (it covers 80% of the Basin in British Columbia, Idaho and Montana above Kootenay Lake). The white sturgeon and bull trout, both considered for listing as threatened or endagered, are present in the Basin.

## 2.7 DESCRIPTION OF EXISTING CONDITIONS

### 2.7.1 Reach–by–reach Description

The Basin's existing water quality conditions will be separated into five major reaches and the following parameters will be discussed: toxicants, heavy metals, turbidity, dissolved gases, temperature, nutrients, pH, sediments, bacteria and radionuclides.

The major reaches are: Origination in British Columbia, Canada to Grand Coulee Dam; Coulee Dam to the Snake River Confluence; Snake River; Snake River Confluence to Bonneville Dam; and Bonneville Dam to the Pacific Ocean. In addition, water quality conditions at Libby and Hungry Horse reservoirs, which are also covered by the Columbia River System Operation Review, will also be described.

Figure 2–4, originally prepared by B.C. Hydro, is a three–dimension illustration of the Columbia River and its major tributaries, including locations and elevations of all existing dams.

Good usable water quality data is generally limited to specific locations, and data available from most of the long term monitoring programs, with the exception of temperature and dissolved gas data, is either outdated or unreliable. Because of this, much of the material within this section will be based on professional judgment of the contributing preparers or generalizations. The need for additional monitoring is discussed elsewhere in this Appendix.

**Libby Water Quality**

The Kootenai River in Montana was impounded by Libby Dam in March 1972 to form Lake Koocanusa. Below Libby Dam, the Kootenai River flows back into Canada to Kootenai Lake, which flows into the Columbia River. Water quality data were collected downstream of Libby Dam by the USGS before and after dam construction. In general, the construction of Libby Dam reduced discharge extremes, increased overall water discharge temperatures, decreased summer discharge temperatures, and decreased nutrient levels in the Kootenai River downstream of the dam (Whitfield and Woods, 1984). Damming of the Kootenai River also increased the pH of the river, although seasonal changes were observed and were proportional to depth of discharge.

Water quality data collected from October 1984 to September 1985 approximately 0.7 mile downstream from Libby Dam, reported pH values from 7.9 to 8.5; water temperatures from 37 to 61°F (2.5 to 16.0°C); dissolved oxygen from 87 to 113 percent saturation; low nutrient concentration (generally <0.1 mg/l, N and <0.01 mg/l P); and low total organic carbon (<2.0 mg/l) (USGS, 1986).

Although highly productive (eutrophic) conditions were predicted for Lake Koocanusa, turbid conditions and physical limnological factors caused low algal productivity (McKim et al., 1976). In addition, Canadian municipal and industrial sources substantially reduced nutrient loading into Lake Koocanusa during the late 1970s. Sediments in Lake Koocanusa are calcareous and low in organic matter, have a silty loam or loam texture, and serve as a phosphorus sink (Iskandar and Shukle, 1981). Combined with the reduced nutrient loading, this may contribute to the low productivity of the lake. During spring snow melt run–off, substantial quantities of suspended sediment are discharged to the Kootenai River downstream of the dam (Ciliberti, 1980).

In 1973, game fish populations were adversely affected by high gas supersaturation levels at least 5 to 6 miles downstream of the Libby Dam (May, 1973). Total gas supersaturation levels of up to 130 percent were observed in some areas of the river (May, 1973). Since Unit 5 began operation in 1984, no spill has been necessary and gas supersaturation levels have generally been below 110 percent.

There were problems associated with contaminants (metals and organochlorides), but these have not been fully investigated with regard to effects on fish. Nutrients have also been mentioned as a concern for Libby Reservoir and the Kootenai River.

A recent report (Knudson, 1994) documents the effects of land and water use activities, especially hydropower operations, logging, mining, and untreated or poorly treated municipal and industrial (pulp mill) wastewater on fish, recreation and in–stream water quality. These activities degraded water quality and habitat in the 1960's and 1970's but were brought under control during the 1980's. An expanded monitoring program is needed to measure the long term effectiveness of the control program. Monitoring and enforcement programs in the Kootenay River Basin are hampered by differences in water quality criteria and standards across the international boundary.

The Kootenai Tribe of Idaho's Environmental Management and Fisheries Departments have been conducting water and sediment quality studies on the Kootenai River and its tributaries. This was prompted by concerns arising from the white sturgeon recovery efforts, and the apparent trophic collapse of the Kootenai River ecosystem. Although few negative water quality impacts have been reported to date, the data collection effort is likely going to continue for some time.

**Hungry Horse Water Quality**

Hungry Horse Reservoir was created in 1953 with the completion of Hungry Horse Dam on the South Fork of the Flathead River, approximately 4 miles from the confluence with the main stem, which subsequently empties into Flathead Lake. Water quality data collected in 1978 indicated that the reservoir is oligotrophic; i.e. low in nutrient input and primary productivity (May and Weaver, 1987). Surface water temperatures vary widely in Hungry Horse, ranging from frozen (32°F (0°C) in winter to over 73.4°F (23°C) in late summer. The reservoir thermally stratifies in summer (typically June through September) but is isothermal (no temperature gradient) in spring and winter. The water volume in the preferred thermal range for cutthroat trout (50 to 60.8°F (10 to 16°C) is greatest in spring and fall (May and Fraley, 1986).

Downstream, hypolimnetic discharges from Hungry Horse have lowered the summer water temperatures and raised the winter water temperatures in the Flathead River from historical levels (Beattie et al., 1988). Cold water released from the deep layers of the reservoir reduces trout growth in the South Fork and mainstem Flathead Rivers to a fraction of pre–dam levels. The Northwest Power Planning Council has called on Bonneville Power Administration and the Bureau of Reclamation to begin actions aimed at installing a temperature selective withdrawal facility at Hungry Horse Dam. This should minimize instances of large, rapid and detrimental temperature fluctuations in the Flathead River.

The dissolved oxygen levels in Hungry Horse Reservoir have been consistently above biologically optimal levels of 7 mg/l, typically in the range of 8 to 10 mg/l. The pH (in 1985) ranged from 7.4 to 8.9, with the majority of values between 7.8 to 8.5 units. Specific conductance ranged between 110 to 150 umhos/cm, on the lower end for productivity (May and Fraley, 1986).

**Reach 1, Origination to Grand Coulee Dam**

The Columbia River begins in Central British Columbia about 400 miles above the city of Castlegar, British Columbia. Major tributaries in this reach are the Kootenay, Pend Oreille, and Spokane River. Lake Roosevelt, created by Grand Coulee Dam, begins below the Canadian Border near the town of Northport, Washington. There are several small towns located on the river in British Columbia. Major industry within this reach is mining, timber, agriculture, hydropower, tourism, and pulp mills. The Hugh Keenleyside Dam in British Columbia is also located in this reach. The purpose of this dam is flood control.

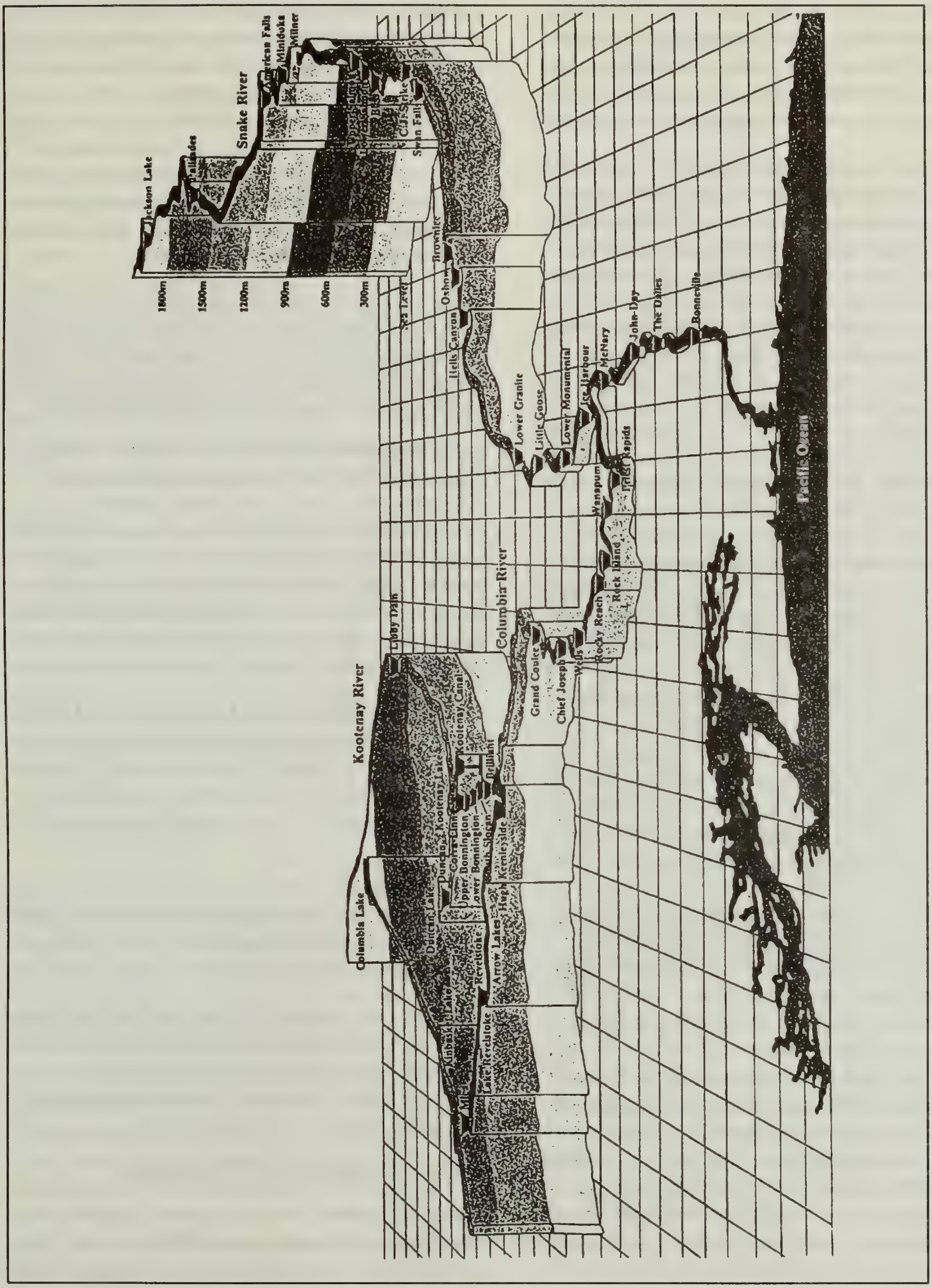


Figure 2–4. The Columbia River and its Tributaries

Water entering the Columbia River from the Kootenay and Pend Oreille Rivers meets British Columbia Ministry of Environment's water quality standards. The Pend Oreille River acts as a major diluter of pollution from Canadian industry located up stream.

Monitoring at International Boundary has shown a dissolved gas problem at certain times of the year. Total dissolved gas supersaturation is associated with the operation of Canadian hydropower and flood control projects in the upper reaches of the basin.

The major contributors to the pollution of the river in this reach for the past 30 to 40 years has been from the Celgar Pulp Mill, located near Castlegar, B.C., and the Cominco Lead and Zinc smelter located in Trail, B.C.

The Celgar Pulp Mill produces a high quality pulp necessary for the production of white paper. The bleaching process used in the past has produced by–products containing large amounts of dioxin, furans, and fibre which have been directly discharged into the river. Studies conducted by Canadian and United States scientists have shown dioxin/furans contamination in the rivers sediments, aquatic invertebrates, and fish. The Celgar Pulp Mill has been upgrading and expanding its facilities during the past few years and has installed new technology and water treatment facilities that will eliminate the discharge of dioxin/furans and fibre. British Columbia Ministry of Environment is presently monitoring the mill for the discharge of other pollutants.

The Cominco lead and zinc smelter is the largest of its type in the world, employing several hundred people. Past operations have been very detrimental to the river's water quality. Studies in Canada and in the United States on Lake Roosevelt have found large amounts of heavy metals and trace elements. The plant has also been discharging 300 to 400 tons of slag per day in the river. This not only scours the river bed, it also deposits harmful material. Since the discovery of contamination of the river by Cominco, Environment Canada, British Columbia Ministry of Environment, and the Lake Roosevelt Water Quality Council have been pressuring Cominco to eliminate discharges of harmful material to the river.

The three entities have also been conducting scientific studies to determine the extent of the pollution and how it is affecting the lake and riverine environment. Over the past 2 years Cominco has taken several steps to eliminate pollution to the river. They have developed an automated spill prevention and clean–up program, constructed ponds and covered stockpiles to prevent erosion to the river, upgraded their water quality treatment facilities, and by 1995 will stop discharging slag into the river.

Other not so major sources of pollution to the river in British Columbia are the Cominco fertilizer plant which discharges phosphorous and the Trail Sewage Treatment Plant that occasionally dumps raw sewage into the river, because of a faulty collection system.

Past and present studies indicate pollution from the Celgar Pulp Mill and Cominco Metals has been significant, especially heavy metals and trace elements. Studies showing dioxin and furans in fish also indicate a major problem area, but more studies must be conducted to determine the amount of dioxin and furans in the deeper sediments and how operation of the system may distribute the toxins into the food chain.

Sources of pollution in the United States to Lake Roosevelt come mainly from old and new mines, agriculture, and logging. The magnitude or extent of pollution is not presently known, but studies are being conducted in the watersheds to determine the impact.

The Spokane River enters Lake Roosevelt about 50 miles down river. The Spokane River's water quality is affected primarily by agriculture, urban development, and industry.

More accurate scientific studies have probably been conducted on this reach than any of the other reaches. More studies and a long term monitoring program need to be developed and conducted to complement the work already completed.

**Reach 2, Coulee Dam to the Snake River**

The major tributaries to this reach of the river are the Okanogan, Wenatchee and Yakima rivers. There is one federal dam in this reach, Chief Joseph Dam, and several mid–Columbia Public Utility District's dams. These are Wells, Rocky Reach, Rock Island, Wanapum, and Priest River Dams. This reach is a major agricultural area producing a variety of food products for animals and human consumption.

There are two large and several smaller irrigation projects within this reach that drain directly or indirectly into the river or its tributaries. The major projects are the Columbia Basin project which extends from Banks Lake to the confluence of the Snake River, and the Yakima Project that extends from northeast of Yakima to the confluence of the Snake River. Irrigation return flows containing nutrients, sediments, and pesticides may impact the water quality of this reach considerably. Other impacts are sedimentation from irrigated farmland and erosion caused by cattle and sheep.

Dams in this reach are operated for flood control, power, and irrigation, and their impacts on water quality are relatively minor compared to pollution problems caused by agriculture and other sources. Some of the larger cities located in this reach may also directly or indirectly impact the rivers water quality. If any of them are discharging directly into the river, they would be required to have a 402 NPDES permit, which is regulated by the State of Washington.

**Hanford Sub–Reach**

In 1943, the U.S. Atomic Energy Commission committed 560 square miles of land in Eastern Washington to the production of radioactive materials for defense purposes. As part of this operation, discharge and disposal of toxic wastes were made to various underground storage sites on the reservation. A total of nine nuclear reactors were also put in service between 1944 and 1987, some of which discharged their cooling water into the Columbia River. For national security reasons, access to specific information on operational and waste disposal practices at Hanford was limited to only those directly involved for many years. Studies on the long–term potential environmental impacts of the operation also have generally not been made public. Because of the reservation's proximity to the Columbia River, any leakage of storage tanks would drain toward the 44 miles of the Hanford. This explains the high interest shown by the public in identifying and characterizing the wastes that are onsite.

Since 1957 the Hanford sub–reach of the Columbia River has been monitored for various contaminants discharged to the River directly or through springs. In addition, some 700 wells, approximately 140 in the near–river area, are monitored quarterly for tracking plumes of contaminants and radionuclides. So far, no impacts were directly observed on the Columbia River water quality as a result of the Hanford operation.

Analyses made in 1988 revealed low levels of long–lived radionuclides at most locations along the Hanford shoreline. Most of these radionuclides were also found in sediment samples. The levels detected are, however, thought to be far below a health hazard or danger to public health and safety.

The mission of Hanford is now changing from nuclear materials production to clean–up and restoration. The U.S. Department of Energy is committed to phasing out liquid radioactive waste discharge to Hanford soils by 1995. Under the current Superfund action spearheaded by the U.S. Environmental Protection Agency a thorough survey of springs along the River was conducted in 1991. Monitoring activities to assess a broad range of radionuclides and hazardous substances are scheduled to continue for a few more years.

More studies of the river and its tributaries need to be conducted in this reach, and the Hanford subreach.

**Reach 3, Snake River**

The Snake River originates in western Wyoming, flows through Idaho, and enters the Columbia River near Pasco, Washington. The major use of Snake River water is for barge traffic, recreation, power, and irrigation. Dams that may affect water quality on the Snake River are Brownlee, Oxbow, Hells Canyon, Lower Granite, Little Goose, Lower Monumental, Ice Harbor, and Dworshak Dams. Dams higher up in the system probably do not directly affect Columbia River's water quality.

Eight long term water quality monitoring sites are located on the Snake River. Monitoring dates range from 1975 to 1992 and are located at Burbank, WA; Ice Harbor, WA; Lower Monumental, WA; Little Goose, WA; Lower Granite, WA; Lower Granite at river mile 120, WA; Anatone, WA; and Weiser, Idaho (see Figure 2–1). The primary parameters measured at these locations were water temperature, specific conductance, dissolved oxygen, and pH. Most of these stations were only sampled once or twice per year and, in most cases, not every year.

The United States Geological Survey has a long term monitoring station on the Clearwater River at Spaulding, Idaho. They also sample for water temperature and specific conductance, suspended sediment, turbidity, total Phosphorous, dissolved oxygen, and pH.

The spill over the dams in the lower Snake River has increased dissolved gas saturation, although pre–dam conditions might have also experienced supersaturation. Total dissolved gas saturation levels in the lower Snake River are influenced by flow from the Clearwater River (including releases from Dworshak) as well as the middle Snake River, and typically range from 105 to 110 percent saturation in Lower Granite forebay during the spring in high flow years. Saturation levels successively increase downstream through the Little Goose, Lower Monumental, Ice Harbor, and McNary forebays when all projects are spilling. Installation of spillway deflectors at Lower Granite, Little Goose, and Lower Monumental dams has reduced the levels of total dissolved gas supersaturation associated with spillway discharges. However, maximum supersaturation ranging from 110 to 140 percent has still been observed for extended periods during high flow events. This exceeds the state standard and federal criteria of 110 percent saturation (Corps of Engineers, 1984–92).

Water storage capacity at the four lower Snake River reservoirs is very limited and retention time is approximately 8 to 20 days, depending on the flows. Therefore, thermal stratification (vertical temperature gradients decreasing from top to bottom) is rare, but during some low flow years, stratification may occur for short periods and range up to 7°F (3.9°C). In general, however, the maximum difference is about 4°F (2.2°C). Temperatures are generally lower during the spring of a high flow year, but they increase in July or August.

Vigg and Watkins (1991) have further characterized temperature in the Snake River as follows:

"Mean water temperature in the lower Snake during 1985–89 was above 70°F (21°C) from 17 July to 19 August; considerable annual variation occurred with temperatures exceeding 70°F (21°C) from 10 July to 14 September in individual years. Based on an analysis of 1938 to 1966 USGS data, the effect of the hydropower system and other anthropomorphic (human–caused) changes on temperature in the Columbia River became apparent in the mid–1950s; the major effect has been shifting temperature maximums so that warmer temperatures occur later in the year (EPA and NMFS, 1971; Crawford et al., 1976). The most significant changes have been above the confluence of the Snake and Columbia rivers. Pre–dam (1955 to 1958) water temperatures were high (greater than 72°F (22°C)) in the lower Snake River during mid–July to late August (FWPCA, 1967). Other human–caused watershed disruptions (e.g., defoliation [loss of riparian vegetation] and water diversion) probably elevated maximum temperatures over historic levels in the Snake River Basin (for example, irrigation–associated influences increased river temperature 6°F (3.3°C) to 7°F (3.9°C) between Parker and Kiona in the Yakima River (FWPCA, 1967)".

The Snake River has a significant effect on the hydrology and water quality of the Columbia River because of the respective volumes of water involved. Large amounts of sediments are transported from the Snake River into the Columbia. If these sediments contain large amounts of contaminants, such as hydrocarbons, pesticides, nutrients, and organochlorines, impacts could be significant.

Commerce or transportation of goods and services to and from the Columbia River up the Snake River to Lewiston, Idaho is very important to the economy of the area. Barging requires dredging of navigation channels deep and wide enough for safe navigation. Dredging can have a significant impact on the hydrology, water quality, and aquatic ecology of the river. Commerce can also pollute the river's water with gas and oil spills and accidental spills of various contaminants from barges.

Agriculture in the drainage basin has an impact on water quality. It is known to contribute large amounts of sediments to the river and other chemicals used for farming. Water quality conditions for other parameters in the middle Snake River have been summarized as follows (Idaho Department of Health and Welfare, 1982).

"The Snake River trend stations have historically recorded escalating concentrations of bacteria, nutrients, and suspended sediment as the river flows from Marsing to Weiser. A current comparison of water quality between Marsing and Weiser cannot be determined due to insufficient data at Marsing; however, the Snake [River] at the Weiser station continues to reflect consistently high nutrients and sediment. Bacterial densities exceed criteria for primary contact recreation (May–September) at Weiser. Subsequent decreases in bacteria and suspended sediment are observed below Hells Canyon Dam, after the river has passed through Brownlee, Oxbow, and Hells Canyon Reservoirs. Nutrients continue to be of concern below the dam accompanied by occasional low dissolved oxygen [concentration] levels. Toxaphene residues, in concentrations associated with reduced growth and reproductive failure, have been detected in fish taken from the Snake River at Weiser and Hells Canyon Dam".

The report also states that non–point source inputs from irrigation returns and grazing areas are the principal pollution problems in the reservoir complex. The EPA has classified the middle Snake River as having marginal water quality (receiving moderate or intermittent pollution) (BPA,1985).

In summary, the waters of the lower and middle Snake River are degraded; the waters are high in bacteria and nutrients, resulting in high productivity. Water temperatures are somewhat elevated and depleted of dissolved oxygen in certain areas. Although not well documented, it is likely that organic residuals associated with pesticide and herbicide applications are also present. All of these observations are consistent with the quality of irrigation return water, which constitutes a high percentage of the middle Snake River flow.

**Clearwater River Water Quality**

Data for the Clearwater River System are limited, although studies are being conducted that may provide useful information. A major human–induced effect on the Clearwater System is Dworshak Reservoir. This storage reservoir is deep (600 feet in the forebay) and narrow; consequently, the lake thermally stratifies every year with a thermocline at approximately 40 to 50 feet. Deep water (below 40 to 50 feet) temperatures remain consistent throughout the year at about 39°F (4°C) to 41°F (5°C). Retention time in the reservoir is about 1 year. The reservoir has been characterized as oligotrophic (i.e., low in productivity and nutrient limited).

The USGS station at Spaulding, Idaho, a National Stream Quality Accounting Network station, provides data on other water quality parameters. Data from the most recent available year are consistent with the oligotrophic characterization of the reservoir and indicate exceptional water quality that is low in dissolved solids and devoid of inorganic contaminants.

**Reach 4, Snake River Confluence to Bonneville Dam**

There are three large dams, one irrigation project and several smaller streams that empty into the Columbia River in this reach. The dams are McNary, John Day, and The Dalles Dams. The Umatilla Irrigation Project is located near McNary Dam. Water quality data for this reach is minimal with the exception of temperature and dissolved oxygen at Umatilla and McNary Dam.

Agriculture in the drainage basin of the river has an impact on water quality, but sufficient data is not available to quantify its impact, if any. Because this reach is below the confluence of the Snake River, dam and reservoir operation and maintenance may have a measurable effect on the distribution of sediments and other contaminants to the Columbia River.

In conclusion more work needs to be done in this reach to determine existing and operational impact on water quality.

**Reach 5, Bonneville Dam to Pacific Ocean**

Bonneville Dam is the last major downstream dam on the Columbia River. Major tributaries in this reach are the Willamette, Lewis, and Cowlitz Rivers. Portland, Oregon and Vancouver, Washington are the largest cities in this reach along with several smaller towns. Commerce traffic is heavy in this reach and industrial and urban discharges numerous.

The latest water quality study for this reach was a reconnaissance survey commissioned by the Lower Columbia Bi–State Water Quality Program. The study was designed to answer general questions regarding possible water quality problems and to determine further study needs in different locations.

The study looked for heavy metals, bacteria, pesticides, PCB's, dioxin and furans, and other conventional pollutants. With the exception of radionuclides, all contaminants were found in either the river's water column, sediments, benthic communities, or many species of fish. The majority, with the exception of organic contaminants in the water column, exceeded state and federal water quality criteria.

Contaminants were found downstream from Portland, Vancouver, St. Helens, Kalama, Longview, and Wauna. They most likely came from sewage treatment plants, pulp mills, barges and ships, marinas, and other large and small businesses. Contaminants found in the river have a detrimental impact, not only on water quality but to the aquatic flora and fauna living in or next to the river. Further studies need to be conducted to determine the severity and source(s) of the pollutants.

Recent investments in pollution abatement by lower Columbia River industries include $38 million by Boise Cascade Corporation at its pulp mill in St. Helens and $18 million by James River Corp at Wauna. Both mills converted from chlorine to chlorine dioxide for bleaching pulp in white paper production. This is expected to substantially reduce chlorine discharges and the trace amounts of dioxin which accompany these discharges.

The impacts of the ocean tide can be felt as far upstream as the Bonneville Dam. Salinity intrusion (salt content of 2 parts per million or more) also affects the lower 20 to 30 miles of the Lower Columbia River. The extent of the intrusion largely depends on the combination of tidal range, river morphology, and streamflow. Based on survey data, a maximum tidal range of 6.9 feet combined with a low streamflow of 110,000 cfs pushed the distance of intrusion to about 25 miles up–river. This distance was reduced to about 20 miles when the maximum tidal range was 9.2 feet and the streamflow reached 182,000 cfs (McConnell et al., 1979). Operations of the dams above Bonneville Dam may play an important role in distributing the contaminants downstream into the estuary, and limiting salinity instrusion upstream.

Materials dredged from the federal navigation channel along the main stem of the Columbia River consists of clean medium and fine sands. Physical analyses of the dredged areas show little change in characteristics over the last 60 years. Because the material dredged is defined as a coarse grain material, is low in organic content, and comes from a high energy environment removed from known contaminant sources, the material dredged from the main ship channel meets exclusive criteria described in the Clean Water Act [40 CFR 230.60 (a), (b),].

Maintenance dredging is coordinated through a public process, and a water quality certification is issued by the States of Oregon and Washington. Both states include provisions regarding allowable mixing zones for impacts related to turbidity and dissolved oxygen. Meeting the criteria has not been a problem in the past because of limited turbidity increase at the dredging or disposal sites. Further, any water quality impacts associated with dredging are temporal in nature, lasting only as long as the operation.

The factors affecting total dissolved gas saturation in the Columbia River are similar to those described earlier for the lower Snake River. When spilling is minimal (September through March), the saturation level is near normal (100 percent). However, total dissolved gas concentrations increase to as much as 140 percent during heavy spill from April through August.

Lower Columbia River water temperatures vary seasonally and have a recorded range from 31°F (−0.5°C) to 75°F (24°C). Winter temperatures (December to March) range from 32°F (0°C) to 48°F (9°C), and from March and June, water temperatures rise to about 58°F (14°C). By August, the river usually warms to its annual maximum average of 68°F (20°C).

Based on the most recent USGS State Water Resources Data Reports, concentrations of dissolved oxygen are relatively high, ranging from approximately 70 to 135 percent saturation, with a mean saturation of 105 percent. Other previous studies have also shown that the pH value generally ranges from 6.4 to 8.5 pH units (Corps, 1977). Fecal coliform bacteria, expressed as Most Probable Number (MPN), have recently ranged from <1 to 120 colonies per 100 ml. Typically, MPN values have been under 40 colonies per 100 ml.

While the Willamette River is not included in the System Operation Review, this major tributary of the Columbia has been a major consideration in regional concerns about water quality for many years. National attention was claimed by Willamette River cleanup efforts in the late 1960s and 70s. Recently, however, new concerns about the river's condition have materialized. In addition to pollution from Portland's combined sewer outflows during storm events, high levels of dioxin and some deformed fish have been found below pulp mills in the Willamette Valley.

**Columbia Slough**

The Columbia Slough is an 18−mile canal which parallels the Columbia River from Fairview Creek in East Multnomah County to Kelley Point Park in North Portland. It is considered one of the most polluted water bodies in Oregon. Until 1948, the slough was regularly flushed by the Columbia River. It was plugged during the Vanport flood of that year when sand filled pipes under the levee at Marine Drive and NE 17th Avenue.

The City of Portland has committed $125 million to eliminate the flow of raw sewage into the slough during storms. But toxic waste from adjacent industries, including serious concentrations of heavy metals, will remain on the bottom of the slough. Pollutants include arsenic, chromium, lead, mercury, and chemicals such as toluene, polychlorinated biphenols, and dioxin. Leaching from the St. Johns landfill and from contaminated groundwater are additional problems. One proposed remedy is to remove the plug and flush the slough but questions have been raised about the impacts of such an operation on Willamette and Columbia River water quality.

### 2.7.2 Water Quality Concerns by Subbasin

Problems identified for the subbasins are summarized in Table 2−2, as directly excerpted from a 1992 EPA's letter report to the Northwest Power Planning Council. As most of them are not well quantified, the list does not indicate how strong the evidence is nor how widespread the problem may be. The lack of understanding is especially true with respect to the combined or cumulative effects of these problems. Temperature and sedimentation are clearly the most commonly identified problems. It should be noted that Table 2−2, Water Quality Concerns by Subbasin, was based on best professional judgment, not on hard data.

## Table 2–2. Water Quality Concerns by Subbasin
(Source: EPA's letter report to NPPC, 1992)

| Subbasins | Water Quality Problems | Data Gaps |
|---|---|---|
| Basin–wide General | Temperature, sedimentation dissolved gas, dioxin PCBs, groundwater | Metals, pesticides |
| Columbia River /estuary | Temperature, PCBs, dioxins, furans, pesticides, metals, bacteria | Industrial organics radionuc. |
| Mainstem below Bonneville Dam | Temperature, PCBs, dioxins, pesticides, metals, bacteria, DO, TSS | fluoride |
| Willamette River | Temperature, PCBs, dioxins, furans, metals, nutrients, pesticides, DO, pH, sedimentation, bacteria | radio–chemicals chemicals |
| Coast Fork Tributaries | Nutrients, DO, pH, sedimentation, temperature, bacteria, mercury (Cottage Grove Reservoir), flows | |
| Coast Range | Bacteria, DO, algae, nutrients, pH, sedimentation | |
| Clackamas | Bacteria, metals | |
| McKenzie | Organics, metals | |
| Molalla/Pudding | Nutrients, DO, pesticides, sedimentation, temperature, bacteria, oil & grease, TSS | |
| Middle Fork Santiam/Calapooia | Bacteria, organics | |
| Tualatin | Nutrients, algae, DO, bacteria, pH, sedimentation, metals, organics, TSS, pesticide | Sediment contaminants |
| Sandy River | sedimentation, DO | temperature |
| Grays River | sedimentation, habitat alteration | |
| Elochoman River /Germany Creek | sedimentation, habitat alteration | |
| Kalama River | | temperature, sedimentation |
| Washougal River | metals, nutrients, sediments, DO, temperature, bacteria, oil, grease, ammonia, pH, chloride | temperature |
| Lewis River | nutrients, sedimentation, DO, temperature, bacteria, ammonia | temperature |
| Cowlitz River | total dissolved gasses, sedimentation, TSS, DO, bacteria, temperature, (Longview ditches: organics, metals, DO, bacteria, oil & grease) | temperature |
| Mainstem, Bonneville to Priest Rapids: | total dissolved gases, temperature, dioxins, furans, pesticides, PCB's, metals, | metals, PCBs, fluoride |

### Table 2–2. Water Quality Concerns by Subbasin – CONT

| | | |
|---|---|---|
| Hood River | pesticides, nutrients, sedimentation, bacteria, oil & grease, aquatic weeds, TSS | |
| Deschutes River | temperature, DO, sediments nutrients, bacteria, aquatic weeds | pesticides |
| John Day River | temperature, sedimentation, nutrients, DO, pH, bacteria, aquatic weeds, habitat alt. | metals pesticides |
| Umatilla River | temperature, sedimentation, pH, DO, nutrients, pesticides, bacteria, aquatic weeds | metals |
| Wind River | | impaired spawning area |
| Big White Salmon | temperature, bacteria | temperature |
| Klickitat River | cold temperature, sediments, DO, bacteria | temperature |
| Walla River | temperature, sedimentation, nutrients, pesticides, salinity, TSS, DO, bacteria | metals |
| Mainstem Snake, mouth to Hells Canyon | temperature, sedimentation total dissolved gases, algae nutrients, DO, organics | pesticides |
| Tucannon River | temperature, bacteria, TSS | |
| Palouse River | sedimentation, nutrients, temperature, bacteria, oil & grease, pH, metals, DO, ammonia | |
| Clearwater River | temperature, sedimentation, metals, habitat alteration, metals, pesticides, nutrients, DO, priority, organics, bacteria, oil & grease, ammonia | metals nutrients, sediments, habitat alteration |
| Grande Ronde R. | temperature & sedimentation, nutrients, BOD, DO, pH, habitat alteration, bacteria | metals |
| Salmon River | temperature, habitat alteration, sedimentation pesticides, ammonia, DO,metals & low pH (Panther Creek), nutrients | metals habitat alteration sediments |
| Imnaha River | temperature, habitat alteration, sedimentation | |
| Snake Mainstem above Hells Canyon Dam | temperature, sedimentation DO, pH, nutrients, bacteria algae, ammonia, pesticides | pesticides |
| Burnt River | temperature & sedimentation, nutrients, DO, BOD, pH, loss of cover | metals |
| Payette River | temperature, eutrophication (Cascade Reservoir), sedimentation, pH, DO, nutrients | metals |
| Owyhee/Malheur Rivers | temperature, sedimentation, pH, DO, nutrients, trace elements (As, HG), pesticides, algae, flow | |
| Boise River | temperature, coliform bact., turbidity, nutrients, DO, pH, BOD, flow, sedimentation, oil & grease | metals |
| Mainstem, Priest Rapids to Chief Joseph | total dissolved gases, dioxins, furans, pesticides, temperature, metals | PCBs, trihalomethane diss. gas |

**Table 2–2. Water Quality Concerns by Subbasin – CONT**

| | | |
|---|---|---|
| Yakima River | temp. (passage & rearing), pesticides, sediments, DO, ammonia, pH, nutrients, algae, bacteria, chloride, metals, priority organics | metals |
| Crab Creek | temperature, sedimentation, nutrients, pH, bacteria, ammonia | pesticides |
| Wenatchee River | temperature, pesticides, sedimentation | metals |
| Entiat River | temperature | |
| Lake Chelan | pesticides, metals, ammonia, nutrients, bacteria | |
| Methow River | temperature, sedimentation | |
| Okanogan River | temperature, sedimentation, pesticides, DO, pH, | DO, pH nutrients |
| Mainstem, Chief Joseph to Canadian Border | metals, dioxins, furans (LK.,Roosevelt), bacteria (Nespelem R.) | dissolved gas |
| Kootenai River | total dissolved gases, | sediments |
| Clark Fork River | metals, sedimentation, habitat alteration | sediments pH, nutrients |
| Flathead River | temperature, too cold, reduced productivity, total dissolved gases | sediments nutrients |
| Pend Oreille/Spokane River | metals (Zn, Cd), PCB's, DO, pesticides, nutrients, pH, sedimentation, ammonia, TSS, nutrients, temp. bacteria, chloride, aquatic weeds | DO, sediments nutrients |

## 2.8 BASINWIDE STATUS OF WATER QUALITY

Water quality parameters which can be affected by reservoir regulation are discussed in general terms in Exhibit A. The status of some of the most important of them, including trends, is given in Exhibit B. This material is entitled "Columbia River System Operation Review, Historical and Current Water Quality Conditions", June 1993, and was prepared by Ebasco Environmental. Figure 2–5 is a graphic summary of water quality concerns in the area covered by the Corps' North Pacific Division.

Dramatic improvement in water quality conditions in the Columbia River Basin is not expected in the near–term. Many current and proposed reservoir operations have an adverse effects. This includes spill to improve fish passage and reservoir drawdown. Both of these measures are intended to promote the recovery of salmon; determining their effectiveness could require years of monitoring.

Controlling point and nonpoint source pollution –– municipal and industrial wastes, soil erosion, return flow from agricultural lands –– is also a long–term endeavor. It depends primarily on the actions of state and federal regulatory agencies. The Corps of Engineers, Bonneville Power Administration, and the Bureau of Reclamation have little direct control over these sources of pollution except to providing flows to dissipate serious discharges when they occur. Because water quality problems are caused by sources both internal and external to the streams, they should be resolved jointly by all interested and affected parties.

Continuation of current system operations is not expected to affect water quality in the Columbia River Basin to any appreciable extent. Such an assumption, however, is not an assured possibility. Public opinion, expressed both nationally and regionally, indicates dissatisfaction with the emphasis on traditional benefits, power generation, flood

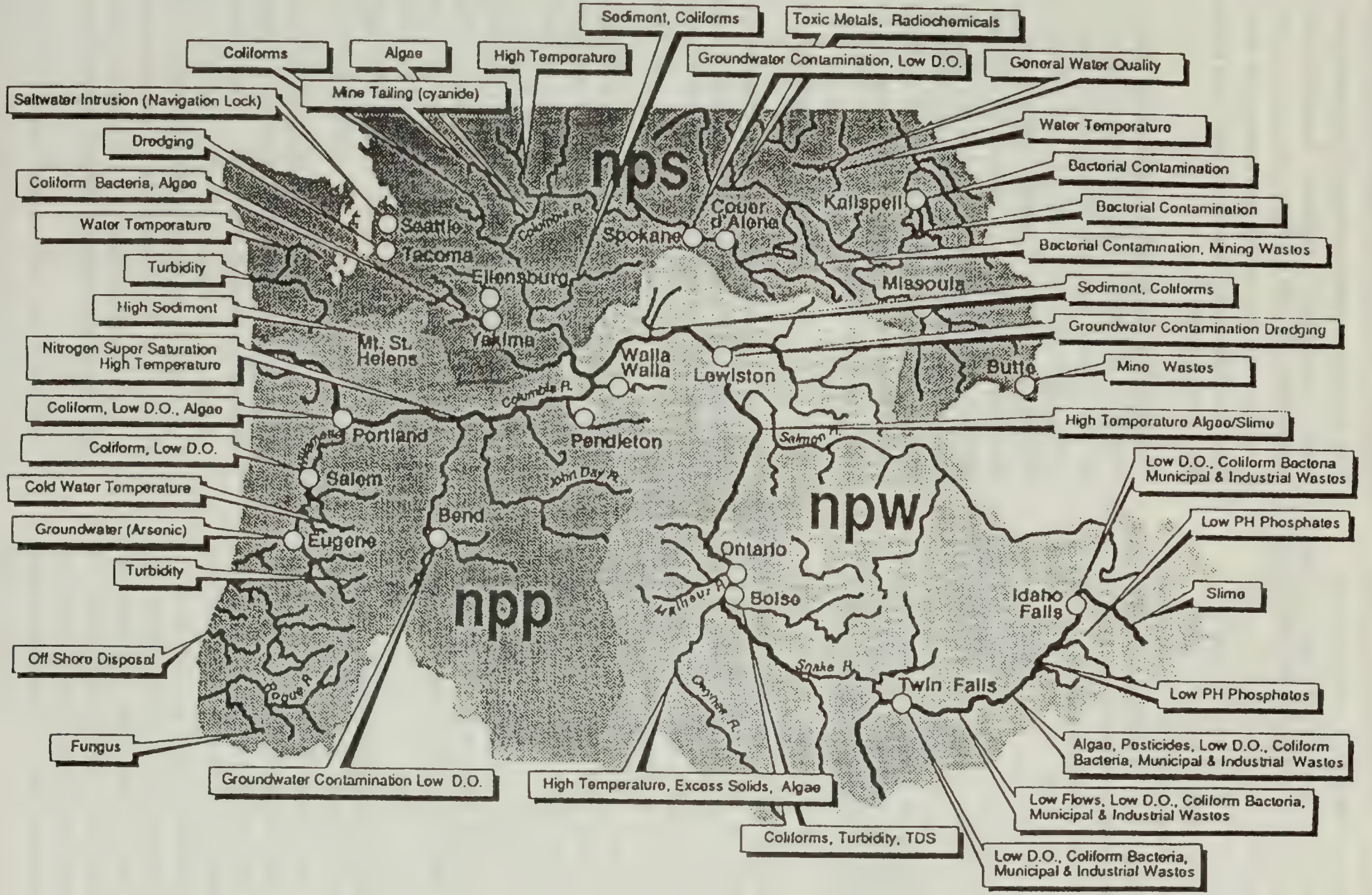


Figure 2–5. US Corps of Engineers North Pacific Division's Water Quality Concerns

control, and navigation. Recreation, environment, and fishery interests are seeking a more active role in the allocation of water resources and day–to–day water management. The Northwest Power Planning Council's Fish and Wildlife Plan requires the augmentation of flows and construction of special facilities for fish. The listing of several salmon species under the Endangered Species Act has required the preparation of recovery plans. This is another major change in the circumstances under which river planning and operation occurred in the past.

## 2.9 CONCLUSIONS

Good water quality is very important to human health, fish and wildlife, recreation, the aquatic environment, and the economy of the Columbia River Basin. The need for protective measures will grow with the normal increases in population and expected industrial development. Because water quality problems are diverse, stemming from both in–stream and out–of–stream sources, all interested and affected parties should join in to provide the required solution(s).

Unfortunately, current water quality information needed for effective water quality management is limited. Because reservoir regulation can affect water temperature, total dissolved gas, and sediment transport, important information about system operations was secured. But impacts on other parameters also need to be assessed to identify cumulative and synergistic effects. Additional holistic water quality studies and long term monitoring are needed to determine how river operations will affect water quality in the future.

# CHAPTER 3

# STUDY METHODS AND SCREENING RESULTS

This chapter presents detailed information about both screening and full–scale study methods. The results of initial screening of alternatives are included but the emphasis is on full–scale analysis, especially the quantitative component. Screening was a stage leading to full–scale analysis and is described in a System Operation Review publication entitled *The Book.*

## 3.1 GENERAL METHODOLOGY

### 3.1.1 Modeling Concepts

Mathematical modeling was used to quantitatively simulate the effects of System Operation Review alternatives on water temperature and dissolved gas saturation.

Initially, hydroregulations for more than 90 alternatives evaluated in screening analysis were produced by the river operation simulation experts (ROSE) work group, using two hydro–simulation models, HYSSR and HYDROSIM. Hydroregulations disclose the magnitude of flows and reservoir elevations based on the objectives of each alternative and the physical and hydraulic capabilities of the system. The amount of water that would be spilled at each project is also indicated.

Involuntary or forced spill occurs when a project has to release more water than its powerhouse can accommodate or when there is no energy load to serve. Voluntary spill is that which is required to meet objectives for fish passage. Water that otherwise would be released through turbines to produce electricity is redirected to spillways to minimize turbine–caused injuries to downstream migrants.

Monthly data on elevations, outflows, and spill at various reservoirs and stream locations for the years between 1928 and 1977 were provided, varying from alternative to alternative. Figures 3–1, 3–2, and 3–3 are sample plots of pool elevation at Grand Coulee Reservoir, and The Dalles project outflow and spill illustrating the type and extent of changes involved. Each year was broken into 14 periods (April and August included two 15 day periods, the remaining 10 months a single 30 day period). This information was used by the water quality work group as input to models assessing the impact of alternatives on water quality parameters.

Impacts of system operations on water temperature and total dissolved gas were measured by different indicators. These included the highest level of temperature and total dissolved gas saturation recorded in given periods and the number of days established thresholds were exceeded. Usually, at least three water years were used to represent dry, medium, and wet flow conditions. Selection of representative years was based on flows and pool elevations expected at key locations. The same years were used in computer runs for all alternatives to provide a common basis for evaluation.

Flows were shaped differently in each alternative and, in any given year, weather condition may differ, independent of run–off conditions. For this reason, three different weather conditions ––1984, 1985, and 1990 –– were used in conjunction with each flow years to assess impacts on water temperature. These are average, below average, and above average weather conditions on the lower Snake River. For the rest of the Columbia River system, they are just three different weather conditions. Emphasis was placed on the lower Snake River because some water temperature control capability exists in this part of the Basin.

To adequately assess water quality impacts, several indices were jointly examined for overall effects. Most important indices routinely include temperature, dissolved gases (nitrogen and oxygen), coliforms, nutrients, and biochemical oxygen demands (BOD). Temperature is one of the major water quality parameters as it influences practically all other water quality variables. High temperature will increase the rate of degradation of organic materials (BOD) but also will decrease the solubility of oxygen in the water. High temperatures are lethal to many organisms. In the Columbia River basin, water temperatures must be within an acceptable range for anadromous fish (salmon) traveling upstream to spawn, and for the juvenile fish moving toward their ocean during their annual outmigration.

Temperature simulation was based on the use of an artificial control volume of water. Changes in the heat content of the control volume are only due to transport of heat across the control volume boundaries. The general methodology was to evaluate individual effects of heat transfer and heat losses, then sum the effects to arrive at the net, overall change in heat content of the control volume.

Quantities of inflows and outflows are already provided by the HYSSR and HYDROSIM model results. Water temperatures of these inflows as well as the tributaries inflows were specified using the three typical years of different temperature conditions mentioned above. Meteorological data including air temperature, dew point, cloud cover, wind speed, and solar radiation were extracted from the National Weather Service's Local Climatological Data Monthly Summaries.

For comparison purposes, current system operations were used as a baseline or reference. The impact of other System Operation Review alternatives on water quality parameters were compared with this base case. Value measures lower than the base case indicate that water quality impacts would be less than those occurring now, and vice versa.

Insufficient data, limitations in the models themselves, and imperfect knowledge about physical processes which were modeled required were acknowledged by the Water Quality Work Group. Modeling reservoir drawdown alternatives in particular has been a challenge, because existing mathematical models have not been validated for these operating conditions. But despite reservations about absolute numbers produced by the analysis, the comparison of value measures produced by the range of alternatives was considered valid. It was also possible to perform a relative ranking of alternatives based on the effects each of them was predicted to have on water temperature, total dissolved gas saturation, and, in full-scale analysis; on the transport of sediments.

### 3.1.2 Analytical Scope and Constraints

#### Parameters Analyzed

For water quality, environmental responses that can be measured and quantitatively predicted include water temperature, dissolved gas saturation, and associated pollutant concentrations or loadings. Since system regulation alternatives considered are generally characterized by flows and end-of-period reservoir pool elevations, only those water quality parameters that are directly affected by flow and reservoir pool manipulations were evaluated. The three parameters evaluated quantitatively were water temperature, total dissolved gas saturation, and sediment transport. Assessment for other parameters was done qualitatively and/or semi-quantitatively.

Water temperature is directly influenced by the amount of water released from each reservoir. Inflow/outflow and reservoir capacity determine the depth of the water stored in that reservoir. For deep storage projects, different water depths mean different intensities of light penetration and, consequently, different water temperatures.

Retention times are determined by release rates. This affects flow velocities and the duration of chemical and biological processes which delay or accelerate the warming of water.

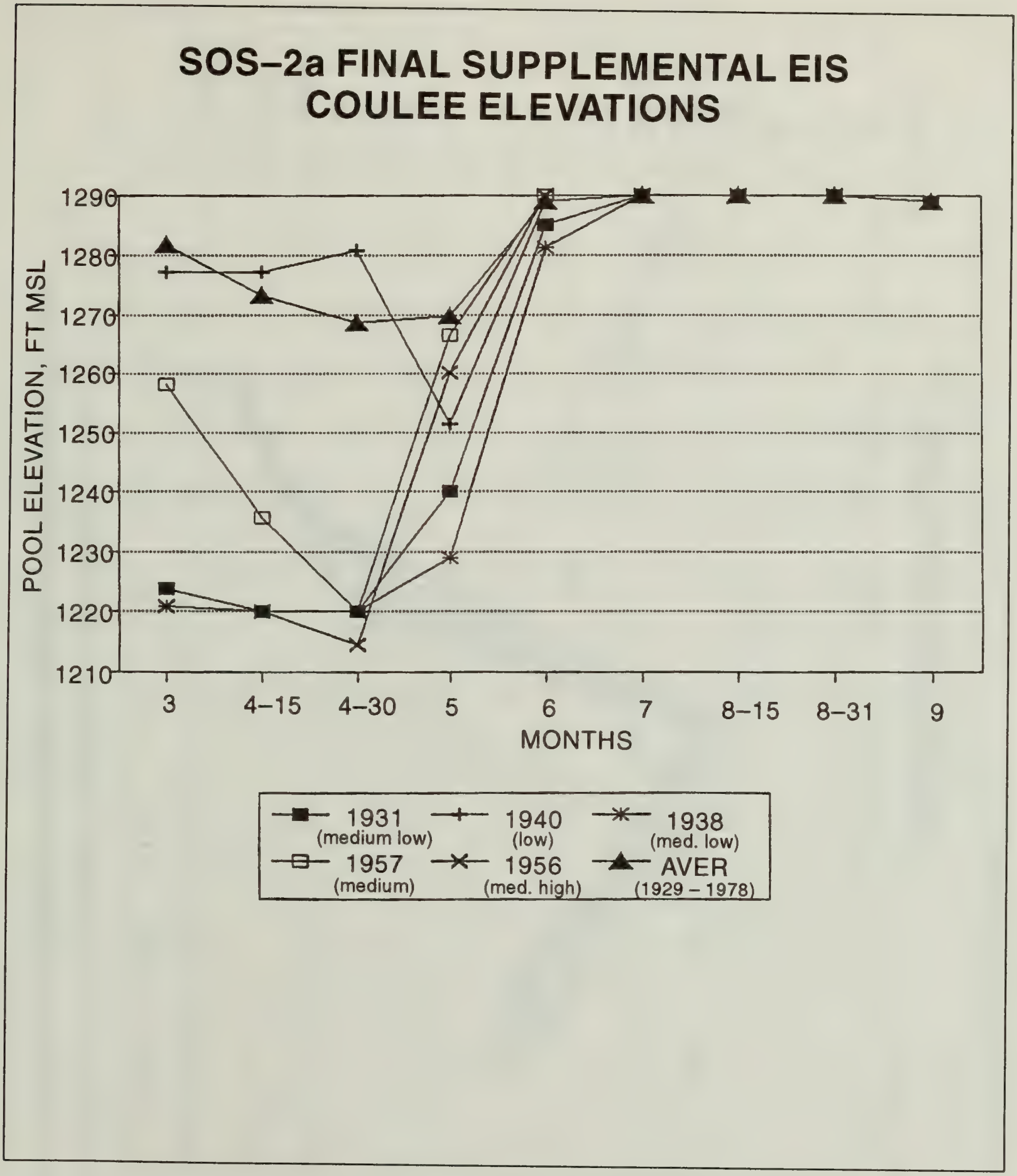


**Figure 3–1. Sample Plot: Grand Coulee Reservoir Pool Elevations**

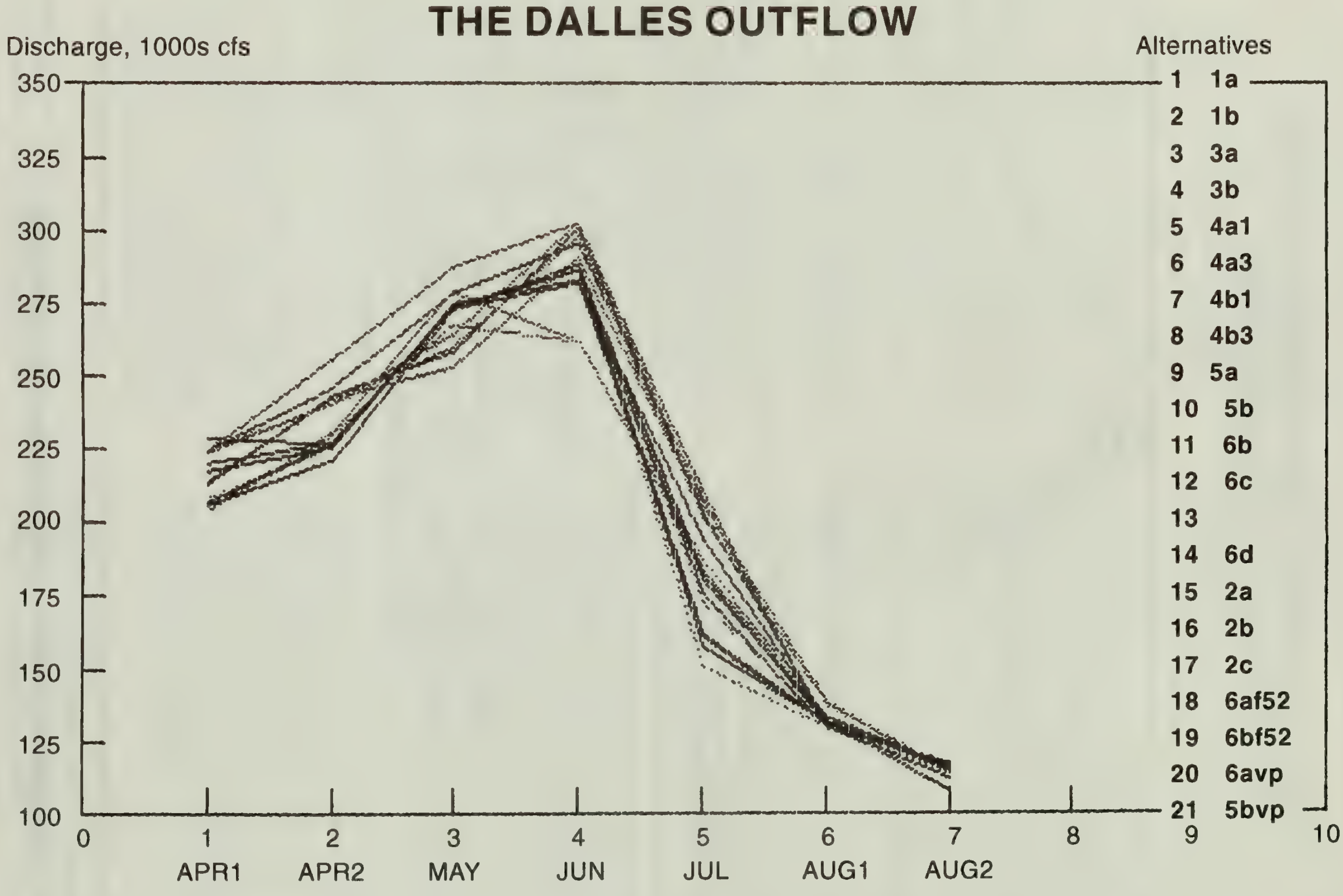


**Figure 3–2.** **Sample Plot: Range of the Dalles Project Outflow for Various SOR Alternatives**

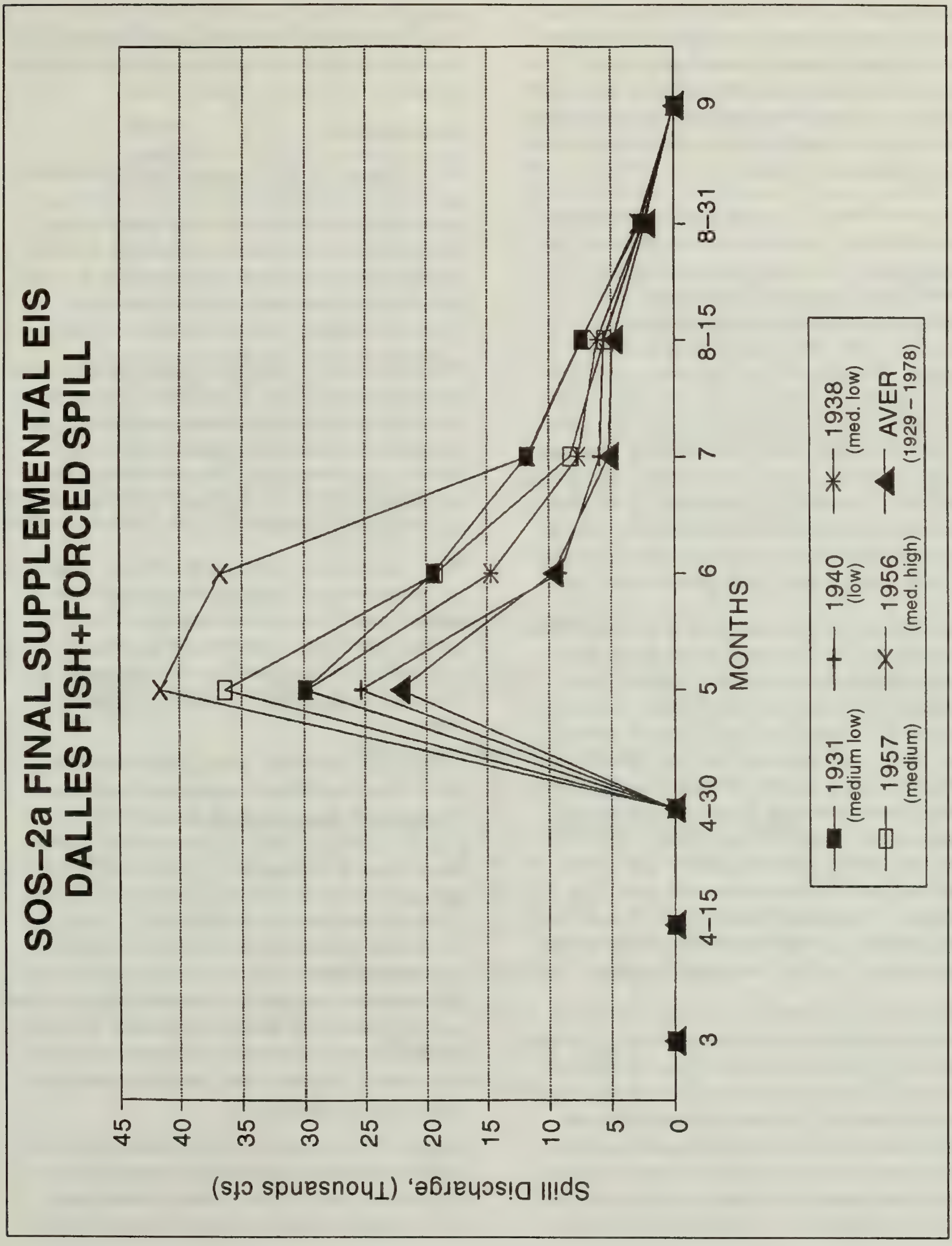


**Figure 3–3.** Sample Plot: The Dalles Spill

Total dissolved gas saturation is determined by the amount of water passing over spillways. The more spill, the higher saturation levels will be in the tailwaters of a given dam. Dissipation of this condition between dams is frequently slow and saturation often increases cumulatively when spill is also occurring at downstream projects.

All streams transport some sediment, which has a natural tendency to deposit when streams enter an impoundment. As a result, the storage capacity of a reservoir may be depleted, and stream channel is usually aggraded for some distance above the reservoir because of backwater effects on sediment transport. Downstream from the dams, some channel degradation and streambank erosion may also occur. Water that is cleared of sediment in a reservoir will attempt to satisfy its unsatisfied transport capacity by eroding the bed and banks of the stream downstream. Erosion and sedimentation are likely to accelerate during reservoir drawdown, because of large pool fluctuations that expose and act on erodible areas that normally lie below the water line.

In addition to water temperature, total dissolved gas saturation, and the transport of sediments, other parameters directly affected by a reservoir system operation include (but are not limited to) turbidity, conductivity, hardness, and total organic carbon. In many cases, toxic chemicals, coliform bacteria, and radionuclides may also be affected because of their linkage to streamflows in terms of transport and concentration. Models to quantitatively assess the impact of System Operation Review alternatives on these contaminants do not currently exist. Only qualitative or conceptual assessments of them were made, assisted by rough correlations when enough data existed to produce meaningful results.

Water quality parameters not directly affected by reservoir operations were not considered in detail in the System Operation Review. These parameters include point and nonpoint sources of sediments and pollutants derived from such sources as land use, logging, access road construction, agricultural and urban development, etc. Data on nonpoint sources of nutrients, which are primarily a function of land use (e.g. fertilization or cattle density), are also lacking. As a result, assessment of long–term, synergistic effects of river system regulation alternatives and waste loads on water quality was addressed qualitatively and only in relative terms.

**Value Measures**

The assessment of water quality effects from system operations was concentrated on times of the year most critical for the parameters in question, April through September for total dissolved gas and July through September for water temperature. For other periods of the year, only a cursory check of the impact of projected outflows and spill was made.

Flows lower than historical minimums could result in inadequate assimilation in the stream reaches involved. Extended spill produces total dissolved gas saturation levels exceeding State standards and harmful conditions for aquatic invertebrates and other aquatic life forms. Adverse, as well as beneficial, effects were considered.

Water Temperature: Assessments of water temperature were based on predicted water temperature profiles inside the reservoirs and along the stream reaches below those reservoirs. Daily predicted temperatures were plotted for each alternative to determine changes, both in absolute values and in timing.

Oregon and Washington water temperature standards allow for no water temperature increases in the Columbia River above 20 degrees C (68 degrees F). Idaho criterion during salmonid spawning season is set at 13 degrees C (55 degrees F). Since there is no uniform water temperature standard in the Pacific Northwest, a threshold of 7.2 degrees C (63 degrees F) was selected for assessing water temperature impact. This is near the upper level of fish resistance (reproduction can still occur) for most species between July through September. The number of days this temperature was exceeded under high, average, and low water conditions is the water temperature value measure.

Figure 3–4 is a diagram of the thermal effects for anadromous salmonids depicting information presented in Columbia River Thermal Effects Study (1971), and an overlay of the Columbia or Snake

River temperature averages. The thermal effects data were developed for the mainstem Columbia and Snake Rivers. Definition of temperature zones follow:

(1) **Resistance:** biological functions are impaired, and fish may die from direct effects of low or high temperature.

(2) **Tolerance:** within the range of normal biological functions, but synergistic effects with other variables (diseases, toxicants, gas supersaturation) may be detrimental – "at which the animal will never die from the effects of temperature alone" (Fry 1947).

(3) **Optimum:** Temperature regime for best health, growth, and reproduction.

Resistance, tolerance and optimum temperature zones are variable in relation to the acclimation temperature of the fish. Listed below are temperature zones described from research conducted on many different anadromous salmonid species and stocks at various life history stages. Included in that research were data for fish challenged with artificially high or low temperatures, but given insufficient time to acclimate at intermediate temperatures. Thus, the temperatures zones displayed may be unnecessarily restrictive for:

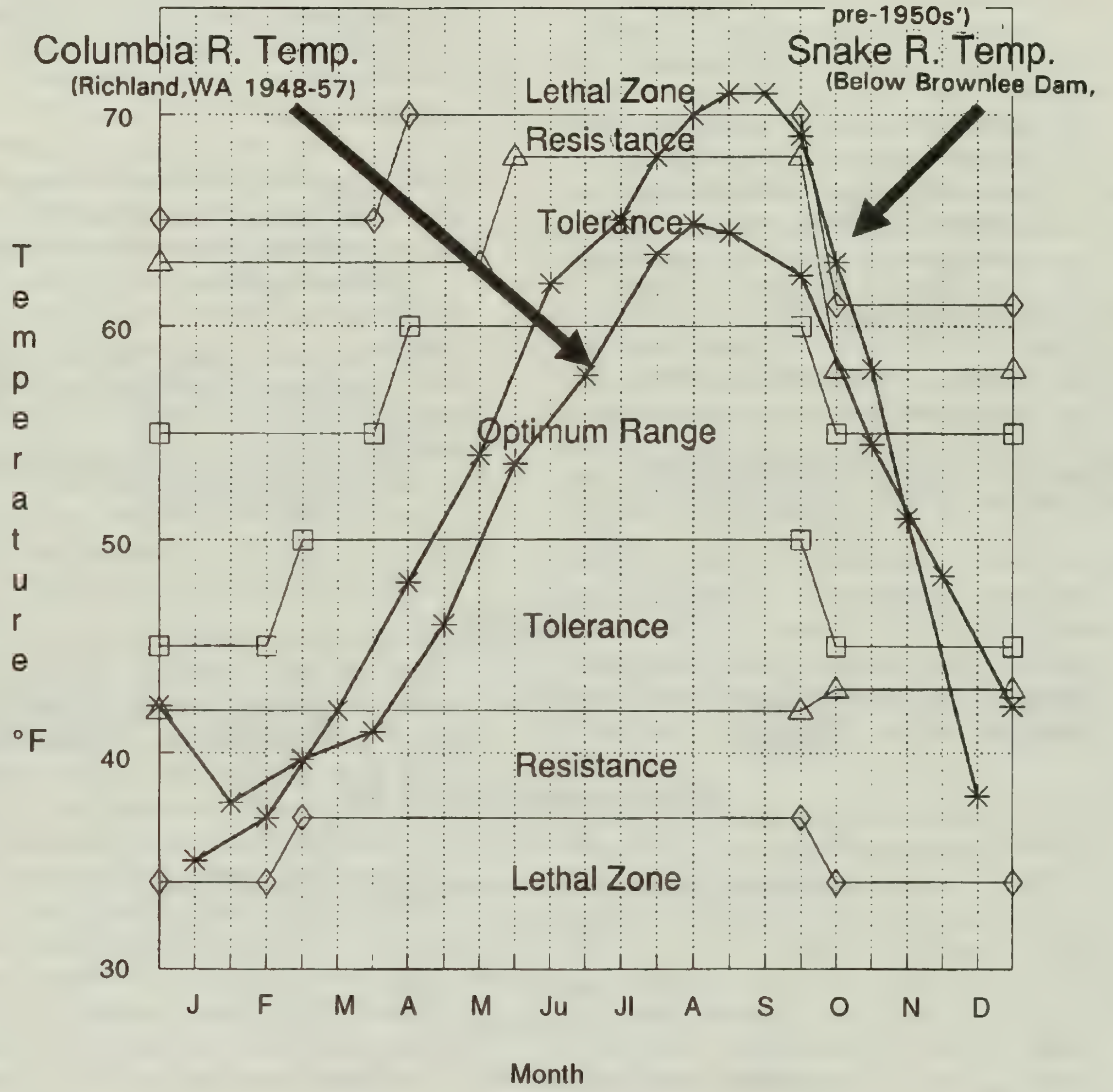
(1) fish residing in the river during the highest and lowest temperature periods; groups that have acclimated to those conditions;

(2) fish in the middle of the date range for an identified life history stage; and

(3) fish which were not the most sensitive at a particular date.

TEMPERATURE °F

| Minimum Resistance | Minimum Tolerance | Optimum | Maximum Tolerance | Maximum Resistance |
|---|---|---|---|---|
| **Early incubation; 1 Oct – 1 Jan** | | | | |
| 34 | 39 | 42–55 58 | 61 | |
| **Later incubation, hatching and pre–emergence; 1 Dec – 15 May** | | | | |
| 34 | 42 | 45–55 63 | 65 | |
| **Rearing; 15 Feb – 1 Oct** | | | | |
| 37 | 41 | 50–60 68 | 72 | |
| **Juvenile and adult migration; 1 April – 1 Dec** | | | | |
| 34 | 42 | 45–60 68 | 70 | |
| **Spawning; 1 Oct – 1 Jan** | | | | |
| 34 | 43 | 45–55 | 60 | 67 |



Source:
EPA Columbia River Thermal Effects Study
vs. Med. Temp. Snake and Columbia 1950's

**Figure 3–4. Recommended Range of Water Temperatures for Snake River Anadromous Salmonids**

Total dissolved gas Saturation: The assessment of this parameter was based on predicted saturation levels in stream reaches below dams where the spill occurs. Daily predicted saturation levels were plotted for each alternative. The number of days three saturation thresholds are exceeded is the value measure. Three thresholds ––130, 120, and 110 percent –– were established. The 110 percent threshold is the current standard in most States, but some researchers believe that most fish species would still survive at saturation levels as high as 120–130 percent saturation for short periods (Weitkamp and Katz, 1980).

Results were summarized for all the project locations simulated in the models. The following three sites are of particular interest: Priest Rapids, on the mid–Columbia River; Ice Harbor, on the Snake River; and The Dalles, on the Lower Columbia River. Thanks to their location, these stations provided a good reflection of the cumulative impacts of actions taken in the river reaches upstream from them. Maximum values of water temperature and total dissolved gas may occur anywhere in the system.

**Constraints**

The accuracy of the water quality data and physical property quantification, and thus the model results, are limited due to a lack of comprehensive water quality monitoring throughout the system, and due to the large geographic scope of the study. Model studies conducted during the Columbia River System Operation Review led to new procedures that advanced the state of water quality technology, but there is not yet enough existing data to thoroughly verify the results. These studies resorted to all known and appropriate data and technology available to determine the effect of system operations within the mainstem Columbia and Lower Snake Rivers.

Quantitative impact assessment using models was subject to several constraints, including (1) lack of daily or hourly flow and pool elevation data, (2) conceptual limitations, (3) limited prediction accuracy, and (4) geographical limits. They applied to all modeling runs.

Hydroregulations provided by the ROSE group included monthly inflows, spill, and end–of–period pool elevations for each alternative. Month–to–month changes in flows were sharp, as they were provided as monthly averages. Minimum and maximum instantaneous flows and daily and hourly flow variations (rates of changes) were not made available. Daily and hourly fluctuations of parameters that are important to certain aspects of water quality had to be determined using flow modulators based on historical data. The assumption of this method is that future system operations will be similar to those in the past, which may be questionable in some cases.

The issues of model limitations and reliability, along with associated risks and uncertainties, are inherent to all modeling activity. Some of the reasons are as follows:

- A model, however sophisticated it may be, is only a simplified version of reality, which usually is much more complicated. While models used by the Water Quality Work Group are based on scientifically sound and proven algorithms, they do not provide all the desired output nor 100 percent accurate predictions.

  For example, the total dissolved gas model available for use only operates on a daily calculation time step. Shorter time steps would have been preferable for greater detail and higher accuracy. Its accuracy (capability to reproduce daily observed saturation levels within 5 percent of absolute values) varies between about 50 to 95 percent, depending on the locations and the general prototype conditions. This means that 50 to 95 percent of the historical values can be replicated by the model within 5 percent of the actual values.

- Model reliability is often in question when a model is used outside the conditions for which it has been calibrated. The prediction related to reservoir drawdown alternatives, which call for operation substantially below the normal operating range, is an example.

Furthermore, the fact that System Operation review does not cover the entire Columbia River basin presents some limitations when specifying initial conditions for the upstream ends of a model (e.g. Canadian and upper Snake River projects). In this case, initial conditions were assumed based on past records.

Finally, the methodology outlined so far was only applied to isolated years, such as high, average or low flow conditions in the basin. The full analysis covering all 50 or 60 years of available hydraulic data would be impractical and was not, for that reason, performed. Because of the relatively limited number of years simulated, no statistical analysis was made.

### 3.1.3 Assumptions

As indicated above, the assessment of water quality impacts was limited to operations altering flows and pool elevations. This required an assumption that other variables were unchanged. Included were weather, water temperature, and saturation levels from Canada and the upper Snake River and effluent concentrations of point and nonpoint pollutants and nutrients.

A snapshot prediction for the year 2023 was attempted to illustrate the sensitivity of these assumptions on the long−term impacts of the alternatives. Major factors involved included primarily predicted changes (increases or decreases) in irrigation and accompanying (positive or negative) changes in the sediment and chemical loading of return flows. Because those changes were believed to be rather limited, no major water quality changes were anticipated within that time frame.

## 3.2 SCREENING ANALYSIS

This section describes the initial screening of alternatives conducted in the early phases of the System Operation Review.

### 3.2.1 Screening Methodology and Models

Water quality screening analysis was confined to an assessment of the impact of alternatives on water temperature and total dissolved gas saturation. For water temperature, the HEC−5Q model was used to predict water temperatures for five typical years ranging from low water conditions to high. Three different weather conditions (below average, average, and above average) were considered and the simulation period was between July and August 31. For total dissolved gas, an empirical model was used to determine saturation levels based on flow spilled at specific dams. Simulation period was April through 31 August.

Value measures were predicted maximum, mean, and minimum water temperatures at three selected locations (Priest Rapids, Ice Harbor, and The Dalles). Modeling uncertainties caused by variations in model coefficients and flow and weather conditions may have affected the analysis results. To provide an insight on the range of expected outputs, the expected 0, 50, and 90 percent values of the value measures were also given. These values established the likelihood (e.g. 10 percent) that the value measure result would be less than or equal to that value.

The alternatives were also rated qualitatively based on the combined impacts on total dissolved gas saturation and water temperature using a scale of 1 to 5, 1 being the most beneficial and 5, the least beneficial.

The conceptual framework, analytical scope, and constraints and assumptions for the screening are generally the same as described in the previous section.

### 3.2.2 Overview of Initial Screening

Results of the initial screening were summarized for all the project locations simulated in the models, including in particular Priest Rapids, on the mid−Columbia River; Ice Harbor, on the Snake River; and The Dalles, on the Lower Columbia River. They were included in an earlier System Operation Review publication entitled, "The Book".

Evaluation of the results obtained in the first−round analysis showed that changes in water temperatures brought about by the various alternatives were relatively small (less than 2 degrees F). This result corroborates with actual observations, when cool water was released from Dworshak Reservoir between 1991 and 1993. No alternatives were found that were fundamentally and irreparably bad or good to water quality. In many instances, impairments to water quality can only be remedied by means other than flow and reservoir manipulations.

The screening analysis confirmed that water temperature control potential is limited in the Columbia River Basin due to the small number of deep reservoirs capable of storing a significant amount of cool water. Of the two reservoirs equipped with selective withdrawal facilities, Libby is too far from the fish migration routes, and Dworshak has too limited a storage in relation to the lower Snake River flows to be fully efficient.

By and large, only a few alternatives have reduction of high water temperatures as a stated objective. None included structural, legal and organizational solutions to specifically address thermal stratification, high or low water temperature, turbidity, low dissolved oxygen, air entrainment, soil erosion, or sediment transport. These measures were outside the scope of the System Operation Review, assuming that pollution would be controlled at the source.

From the standpoint of total dissolved gas, alternatives calling for the most spill are always worst. All dams have a potential for impacting total dissolved gas saturation and little dissipation occurs once saturation reaches high levels.

### 3.2.3 Observations and Recommendations arising from Screening

- Total dissolved gas saturation in the river reaches covered by the System Operation Review depends upon the saturation level of the flows coming from outside the "Basin", from Canada and, to some extent, the Upper Snake River. The contribution from those two sources cannot be ignored.
- On a systemwide basis, alternatives that look good for water temperature are not necessarily good for total dissolved gas, and vice–versa. This required assessment of each of the two criteria separately.
- A ranking based on the summation, with equal weight, of water temperature and dissolved gas impacts would be skewed toward dissolved gas, because impacts on dissolved gas saturation are more pronounced than those on water temperature.
- Sources of pollution not directly affected by system operations must also be taken into account. These include irrigation return flows, effluent contaminant loadings, sewerage outfalls, and groundwater movement.

The following general recommendations were derived after the screening was completed:

- Use of storage from Dworshak and other deep impoundments for the purposes of controlling downstream stream water temperature shows some promises and deserves further review.
- Spill ought to be used sparingly to avoid total dissolved gas saturation that could exceed the state standard and create serious problems for fish (which the standard was supposed to protect).
- Large, rapid reservoir pool fluctuations should be minimized because of potential impacts on bank erosion, sediment resuspension, recreation, resident fish, and reservoir eutrophication.
- Minimum in–stream flow requirements for fish and aquatic life or assimilative capacity (whichever is less) must be met. Providing lower than existing historical flows at any site could violate those minimum requirements.
- Although nutrients cannot be controlled by reservoir operations, their quantities in the river may be related to project operations. In this regard, the use of Libby regulation to control its nutrients concentration may be worth investigating.

The screening of preliminary alternatives described in "The Book" yielded ratings shown in Table 3–1. These ratings used alternative 2c as base case.

### Table 3–1. Results of Alternatives Screening

| Alternatives No. | Symbols | Water Quality Parameters TDGS (1) | WT (1) | Overall (2) | Observations |
|---|---|---|---|---|---|
| 1 | AMG_BBPA | | | 3 | some spill for fish |
| 2 | AMG_BCOE | | | 3 | – – ditto – – |
| 3 | AMG_TAR1 | | | 3 | |
| 4 | AMG_TAR2 | −1 | | 4 | spill @ IHR |
| 5 | AMG_TAR3 | 1 | | 2 | minor TDG improvement |
| 6 | AMG_FEE | −1 | | 4 | |
| 7 | AMG_URCB | | | 3 | |
| 8 | AMG−URCC | | | 3 | |
| 9 | AMG−SRFL01 | −2 | | 5 | spill @ PRD and IHR |
| 10 | AMG−SRFL02 | −1 | | 4 | Slight decr. Lo. Col. |
| 11 | AMG−SRFL03 | −2 | | 5 | high spill @ PRD/IHR |
| 12 | AMG−SRFL04 | −1 | | 4 | some improv. @ TDA |
| 13 | AMG−SRFL05 | −2 | | 5 | high spill @ IHR |
| 14 | AMG−SRFL06 | | | 3 | some TDG improv. @ TDA |
| 15 | AMG−SRFL07 | | | 3 | ditto |
| 16 | AMG−SRFL08 | | | 3 | ditto |
| 17 | AMG−WASH | | 1 | 2 | rel. for temps control |
| 18 | ANA−EM1 | −2 | −2 | 5 | excessive spill/WT |
| 19 | ANA−FU1 | −2 | | 5 | spill PRD and TDA |
| 20 | ANA−FL1 | | −1 | 4 | +TDG and −WT @ TDA |
| 21 | ANA−FL2 | | −1 | 4 | +TDG @ Col., −WT @ IHR |
| 22 | ANA−FL3 | | 1 | 3 | +.TDG @ TDA, −WT Sn/Col |
| 23 | ANA−4YRFDST | | 1 | 3 | ditto |
| 24 | ANA−4YRFDST2 | | | 3 | +TDG @ TDA, −WT |
| 25 | ANA−4YRALST1 | −2 | | 5 | spill @ PRD, TDA |
| 26 | ANA−4YRALST2 | | | 4 | +TDG @ TDA, −WT |
| 27 | AMG−CBFWAB | | 1 | 2 | decr. WT |
| 28 | AMG−CBFWAMODB | 1 | | 2 | decr. WT @ IHR |
| 29 | ANA−FISH | | | 3 | |
| 30 | ANA−STEP1 | | 1 | 2 | decr. WT @ IHR |
| 31 | ANA−STEP2 | | 2 | 2 | decr. WT @ IHR |
| 32 | ANA−STEP3 | | 2 | 2 | ditto |
| 33 | ANA−STEP4 | | 2 | 2 | ditto |
| 34 | ANA−STEP5 | | 2 | 2 | decr. WT |
| 35 | AMG−GOAL | | | 3 | |
| 36 | AMG−NPPC1 | | | 3 | |
| 37 | AMG−NPPC2 | | | 3 | |
| 38 | AMG−92EIS | | | 3 | |

NOTES: (1) using −2 to +2 rating system (−2 being worse) relative to base case
(2) using 1 to 5 rating system (1 being best) relative to base case
TDG = total dissolved gas saturation
WT = water temperature

## Table 3–1. Results of Alternatives Screening – CONT

| Alternatives<br>No. Symbols | Water Quality Parameters<br>TDGS (1) | WT (1) | Overall (2) | Observations |
|---|---|---|---|---|
| 39 AMG–NMFS | | 2 | 2 | temps. red. @ IHR |
| 40 AMG–NPPCF | | | 3 | |
| 41 AMG–URC50 | –1 | | 4 | |
| 42 ROS–XXOBS | | | 3 | |
| 43 FLD–VARQ | | | 3 | |
| 44 AMG–RRPL01 | | | 3 | |
| 45 AMG–RRPL02 | | | 3 | |
| 46 AMG–RRPL03 | | | 3 | |
| 47 AMG–RRPL04 | | | 3 | |
| 48 AMG–RRPL05 | | | 3 | |
| 49 AMG–RRPL06B | | –1 | 4 | spill @ Snake projects |
| 50 AMG–RRPL07B | | –1 | 4 | ditto |
| 51 ECN–CBFWA | 1 | 1 | 2 | |
| 52 ECN–CBFWAMOD | 1 | 2 | 2 | |
| 53 AMG–DRAWB | –1 | 1 | 4 | spill @ Snake projects |
| 54 ECN–NPPC85 | | | 3 | |
| 55 FLD–NOSYS (RES–STBLPL) | | | 3 | |
| 56 RES–FULPL | –1 | | 4 | some spill systemwide |
| 57 RES–WRT | | | 3 | |
| 58 RES–MAX | | | 3 | |
| 59 REC–OPTP | | –1 | 4 | some spill systemwide |
| 60 REC–OPTF | | –1 | 4 | |
| 61 REC–ACC | | –1 | 4 | |
| 62 IRR–OPT1 | | –1 | 4 | some spill systemwide |
| 63 IRR–OPT2 | | –1 | 4 | ditto |
| 64 IRR–OPT3 | | –1 | 4 | ditto |
| 65 RES–IRRF | –2 | | 5 | spill @TDA,PRD |
| 66 WLD–IDEAL | –1 | | 4 | spill @TDA |
| 67 WLD–REAL | | | 3 | |
| 68 AMG–POOL | | –1 | 4 | affects TDA |
| 69 AMG–POOL2 | | –1 | 4 | affects TDA |
| 70 RES–SWAP | 1 | | 3 | |
| 71 RES–COMP | | –1 | 4 | affects IHR |
| 72 RES–FLD | | –1 | 4 | |
| 73 RES–FEC | | –1 | 4 | |
| 74 REC–OPTP2 | –1 | | 4 | |
| 75 REC–OPTF2 | –1 | 1 | 4 | |

NOTES: (1) using –2 to +2 rating system (–2 being worse) relative to base case
(2) using 1 to 5 rating system (1 being best) relative to base case
TDG = total dissolved gas saturation
WT = water temperature

**Table 3–1. Results of Alternatives Screening – CONT**

| Alternatives No. Symbols | Water Quality Parameters TDGS (1) | WT (1) | Overall (2) | Observations |
|---|---|---|---|---|
| 76 REC–ACC2 | | –1 | 4 | |
| 77 PWR–CPMA | | | 3 | |
| 78 PWR–AVOP | | | 3 | |
| 79 AMG–WCV | | | 3 | |
| 80 AMG–CORPSBOR | | | 3 | |
| 81 AMG–CAN | | | 3 | |
| 82 AMG–RRPLSC | | –1 | 4 | |
| 83 AMG–RRPL7C | 1 | –1 | 4 | |
| 84 AMG–DRAWC | | –1 | 4 | |
| 85 ANA–FU1B | | –2 | 5 | spill @ PRD, IHR |
| 86 FLD–NOSYS2 | –1 | | 4 | |
| 87 FLD–VARQ2 | –1 | | 4 | affects TDA |
| 88 AMG–92EIST | | 2 | 2 | decr. WT |
| 89 RES–IRRFL02 | –2 | | 5 | spill @ PRD, IHR |
| 90 AMG–IRRFLO | | –1 | 4 | |
| 91 AMG–IRRFLO2 | 1 | 1 | 2 | |

NOTES:
(1) using –2 to +2 rating system (–2 being worse) relative to base case
(2) using 1 to 5 rating system (1 being best) relative to base case
TDG = total dissolved gas saturation
WT = water temperature

## 3.3 FULL–SCALE ANALYSIS

After the initial screening, a total of seven system operational strategies (SOS) were developed. They included: 1) pre–Endangered Species Act operating conditions; 2) current (1992) operations; 3) flow augmentation schemes; 4) stable storage project operation; 5) natural river operation; 6) fixed lower Snake River reservoir drawdown; and 7) Federal resource agency alternatives. Procedures for conducting full–scale analysis of these strategies are described below. They were consistent with the conceptual framework, analytical scope, constraints, and assumptions discussed above.

### 3.3.1 Methodology/Models Used

The water quality parameters evaluated in full–scale analysis included water temperature, total dissolved gas saturation, and, for drawdown alternatives, sediments transport. For certain operating scenarios, efforts were also made to evaluate turbidity, heavy metals, and other contaminants. The following models were used in the full–scale analysis: HEC–5Q, for water temperature; GASSPILL, for total dissolved gas; and HEC–6, for erosion and sediment transport. All three were developed by the Corps of Engineers. More detailed description on the models and their respective accuracy will be provided in later sections.

System operation alternatives were also evaluated under extreme and average environmental conditions to predict the worst case and average scenarios for each alternative. The influence of river discharge was determined to be the most important environmental factor on water quality in the Columbia River system. A minimum of three years were selected from the past 50 years to represent the low, medium and high flow conditions depending on the alternatives under consideration.

The simulation period was from April 1 to August 31 for HEC−5Q, April 1 through September 30 for GASSPILL, and year around for HEC−6. Daily time steps were used in all three. Five flow years were selected for water temperature simulation, six years for total dissolved gas, and three years for sediments. An effort was made to cover a full range of spill and reservoir pool conditions at critical locations (Grand Coulee, Brownlee, and Dworshak Reservoirs for pool elevation; and Priest Rapids, Ice Harbor, and The Dalles Dams for spill). The selected years were by no means the only set of years that met the stated objective; other slightly altered combinations of years could also have been used. Table 3−2 shows where the selected years fit with respect to pool elevation and spill.

**Table 3–2. Significance of Selected Years With Respect to Pool Elevation and Spill**

| | <..Pool Elevation..> | | | <..... Spill......> | | |
|---|---|---|---|---|---|---|
| ALT | Max. | Ave. | Min. | Max. | Ave. | Min. |
| 1a | 1929 | 1962 | 1974 | 1974 | 1959 | 1973 |
| 2c | 1929 | 1953 | 1974 | 1974 | 1959 | 1973 |
| 5b | 1963 | 1962 | 1974 | 1974 | 1959 | 1973 |
| 6b | 1963 | 1962 | 1950 | 1974 | 1959 | 1973 |
| 6c | 1963 | 1953 | 1950 | 1974 | 1959 | 1973 |
| 6d | 1929 | 1962 | 1974 | 1974 | 1959 | 1973 |

Relative significance between the various years in term of run−off magnitude is shown in Table 3−3.

**Table 3–3. Annual Run–off Magnitude at The Dalles, Priest Rapids, and Lower Granite Dams, 1929–1978.**

| | ...............FLOW RANK............. | | | |
|---|---|---|---|---|
| Year | Annual Runoff (MAF) | The Dalles | Priest Rapids | Lower Granite |
| A. HIGH RANGE | | | | |
| 1955−1956 | 184 | #1 | #2 | #6 |
| 1971−1972 | 181 | #2 | #4 | #1 |
| 1973−1974 | 174 | #3 | #5 | #3 |
| 1950−1951 | 171 | #4 | #3 | #8 |
| 1964−1965 | 167 | #5 | #10 | #4 |

## Table 3–3. Annual Run–off Magnitude at The Dalles, Priest Rapids, and Lower Granite Dams – CONT

| Year | ...............FLOW RANK............. | | | |
|---|---|---|---|---|
| | **Annual Runoff (MAF)** | **The Dalles** | **Priest Rapids** | **Lower Granite** |
| 1933–1934 | 166 | #6 | #1 | #34 |
| 1947–1948 | 165 | #7 | #6 | #9 |
| 1975–1976 | 162 | #8 | #11 | #5 |
| 1968–1969 | 161 | #9 | #7 | #12 |
| 1970–1971 | 159 | #10 | #18 | #2 |
| Average | 169 | | | |
| B. MEDIUM HIGH RANGE | | | | |
| 1951–1952 | 154 | #11 | #13 | #7 |
| 1959–1960 | 151 | #12 | #8 | #21 |
| 1956–1957 | 150 | #13 | #16 | #11 |
| 1960–1961 | 145 | #14 | #9 | #35 |
| 1974–1975 | 143 | #15 | #20 | #13 |
| 1953–1954 | 142 | #16 | #15 | #24 |
| 1946–1947 | 141 | #17 | #17 | #20 |
| 1958–1959 | 141 | #18 | #19 | #14 |
| 1942–1943 | 141 | #19 | #29 | #10 |
| 1948–1949 | 140 | #20 | #22 | #15 |
| 1954–1955 | 138 | #21 | #12 | #37 |
| Average | 144 | | | |
| C. MEDIUM RANGE | | | | |
| 1949–1950 | 137 | #22 | #24 | #16 |
| 1966–1967 | 137 | #23 | #14 | #28 |
| 1945–1946 | 135 | #24 | #26 | #18 |
| 1957–1958 | 133 | #25 | #31 | #17 |
| 1932–1933 | 132 | #26 | #23 | #32 |
| 1937–1938 | 131 | #27 | #27 | #27 |
| 1967–1968 | 130 | #28 | #21 | #31 |
| 1963–1964 | 129 | #29 | #28 | #22 |
| 1952–1953 | 127 | #30 | #32 | #26 |
| 1952–1953 | 126 | #31 | #35 | #25 |
| Average | 132 | | | |
| D. MEDIUM LOW RANGE | | | | |
| 1965–1966 | 125 | #32 | #26 | #33 |
| 1969–1970 | 124 | #33 | #40 | #19 |

## Table 3–3. Annual Run–off Magnitude at The Dalles, Priest Rapids, and Lower Granite Dams – CONT

| | ............... FLOW RANK............. | | | |
|---|---|---|---|---|
| **Year** | **Annual Runoff (MAF)** | **The Dalles** | **Priest Rapids** | **Lower Granite** |
| 1931–1932 | 124 | #34 | #30 | #36 |
| 1977–1978 | 123 | #35 | #37 | #23 |
| 1941–1942 | 122 | #36 | #39 | #30 |
| 1961–1962 | 122 | #37 | #38 | #29 |
| 1935–1936 | 121 | #38 | #33 | #38 |
| 1934–1935 | 114 | #39 | #34 | #47 |
| 1972–1973 | 114 | #40 | #36 | #40 |
| 1939–1940 | 110 | #41 | #42 | #42 |
| 1938–1939 | 109 | #42 | #43 | #43 |
| Average | 119 | | | |
| E. LOW RANGE | | | | |
| 1944–1945 | 103 | #43 | #45 | #39 |
| 1976–1977 | 103 | #44 | #41 | #48 |
| 1943–1944 | 101 | #45 | #46 | #41 |
| 1928–1929 | 101 | #46 | #44 | #44 |
| 1940–1941 | 98 | #47 | #48 | #45 |
| 1929–1930 | 91 | #48 | #49 | #46 |
| 1930–1931 | 90 | #49 | #47 | #50 |
| 1936–1937 | 90 | #50 | #50 | #49 |
| Average | 97 | | | |

The number of days water temperature and total dissolved gas are predicted to exceed selected threshold values was used to assess the effects of alternatives on those two water quality variables. Warm water and/or high total dissolved gas saturation periods are especially targeted during this assessment for each of the flow years, including the highest, lowest and average flow years.

For sediment evaluation, the HEC–6 sediment transport model was used to determine the annual transport and deposition of silt, sand, and clay for the first and fifth years at Lower Granite Reservoir for each of the reservoir drawdown alternatives.

A graphic display was produced showing the amount of sediment (in three sizes) for each alternative at various locations along the length of the Lower Granite reservoir. An estimate was also made of the volume of material subject to erosion in the other three lower Snake River reservoirs. Finally, the amount of turbidity these concentrations of sediment could create was predicted.

**Methodology for Water Temperature Modeling**

The general methodology was the same as that used in screening analysis. Daily water temperature simulation was performed with the COLTEMP model using the five flow years listed below. For full–scale analysis, however, the simulation period was a month longer, from April 1 through September 30. The Libby and Hungry Horse Reservoirs were separately modeled.

The five flow years were selected to provide a typical range of low to high pool elevations and flows at major storage projects, Grand Coulee, Dworshak, and Brownlee. They included 1929 (low), 1959 (medium high), 1962 (medium low), 1973 (medium low) and 1974 (high). These were not the same years (1931, 1940, 1938, 1957, and 1956) used in screening analysis, which were directly assigned by the SOR project managers to all work groups.

Another difference was that flow simulation, in screening, was based on a 50–year (1928–78) refill study, with each year starting from the same initial reservoir elevations. Full–scale analysis was based on a 50–year continuous simulation. Each flow year begins at the pool elevations where the previous year ended.

Three different weather conditions (below average, average, and above average) were again used in conjunction with each of the five flow years. Storage versus elevation curves for lower Snake River reservoirs were revised to accommodate the lower range called for in drawdown alternatives.

Water temperature objectives were again based on fish survival. The target temperature for Dworshak Reservoir outflow was set at 45 degrees F for all alternatives when storage water for meeting that objective was available. Results were tabulated on a day to day basis to facilitate plotting and analysis.

The (limited) effect of water from Libby and Hungry Horse Reservoirs on lower river water temperatures was not predicted. By the same token, no attempts were made to operate upper basin projects to maximize their influence on lower river water temperature. There were, however, water temperature needs for resident fish at and below all projects, including Libby and Hungry Horse. Water temperature profiles of these projects, produced by the resident fish work group, are included in Exhibit E. These profiles were generated on a thermal model originally developed by the U.S. Geological Survey (Ferreira et al., 1992).

**Methodology for Total Dissolved Gas Modeling**

Different input requirements prompted a different methodology for the total dissolved gas model. The question to be answered was, how much total dissolved gas (TDG) will be generated at each project? The following years were analyzed based on their potential for creating high total dissolved gas saturation:

| | |
|---|---|
| high: | 1974* |
| average: | 1959*, 1938, 1962 |
| low: | 1973*, 1977 |

The year(s) that are most common to alternatives are marked with an asterisk. For example, the high flow year of 1974 resulted in high spill for all alternatives. However, more than one flow year was needed to reflect average and low spill conditions for all alternatives. Hence, the need for using two additional flow years so that all alternatives experience high, average and low flow conditions at least once.

For alternatives that do not involve drawdown of Lower Snake River reservoirs, it was assumed that all run–of–the–river projects would be operated as they were in 1986, the last of the most recent high flow years. A pre–processor auxiliary program was used to extract monthly (or semi–monthly) flows from the hydroregulations for a given alternative. Data for all 50 years were processed by the ROSE Work Group but only the results of the six years listed above were extracted for further water quality analysis.

Selected flows from the hydroregulations were modulated using 1986 data as a template; the same period flow averages were maintained. This was predicated on the assumption that future daily flow variations caused by system operation within 15 or 30 day periods would be similar in shape to 1986 fluctuations. The shape of the daily flow fluctuation is important; it may lead to days of forced spill in months where monthly spill values alone do not suggest any spill because of averaging.

Adjustments were made to correct modulated flow changes between a period (P) to the next period (P+1), and to ensure that these daily changes were kept at or below the actual maximum daily changes observed in 1986 for all stations.

Local inflows pre–processed for each station for all 50 years (1928–77) were used to calculate daily inflows to a project. These inflows are the sum of daily outflow from a reservoir upstream from that project and the average local inflow between the reservoir and the project. There were two exceptions:

(1) for McNary (MCN), daily inflow was calculated as the sum of daily outflows from Priest Rapids (PRD) and Ice Harbor (IHR), and the average period tributary inflows between PRD, IHR and MCN;
(2) for Lower Granite (LWG), daily inflow was calculated as the sum of daily outflow from Dworshak (DWR) and Brownlee (BRN), and the average period tributary inflows between DWR, BRN and LWG Dams.

In both cases, flows were appropriately lagged to reflect the relevant travel times involved.

The required spill for fish passage was stated in terms of ratios of daily flows (see Table 3–4). These ratios were the same as those used in the hydroregulations for each time period. Forced spill due to plant capacity being exceeded was calculated as the difference between daily outflows and specific plant capacity values.

For alternatives with no reservoir drawdown it was assumed that pool fluctuations would remain relatively small. Therefore, the same 1986 daily flow fluctuation pattern was used for both forebay and tailwater elevations. In drawdown alternatives, wide variations in pool elevations required changes in reservoir forebay and tailwater elevations. In these cases, lower Snake River reservoirs forebay elevations were interpolated linearly between end–of–period elevations calculated in the hydroregulations. Tailwater elevations were determined from flow versus elevation rating tables for each of the projects involved. Adjustments were made to ensure that monthly values generated by the hydroregulation model were realistically used in a daily simulation model such as HEC–5Q and GASSPILL.

A spill–for–fish–passage requirement was assumed at Ice Harbor Dam, except in the natural river scenario. In this case, pool elevation is below elevations that cause the powerhouse to become inoperable. A "no voluntary spill for fish" concept was also assumed at Lower Granite (LWG), Little Goose (LGS) and Lower Monumental Dams (LMN). Fish collection facilities at those projects are expected to have been relocated to lower elevations by the time the drawdown operation is implemented and these projects would continue as collection sites.

Three levels of spill–for–fish–passage were used depending on the alternatives (see Table 3–4). The first level was applied to pre–ESA operation alternatives, the second level to options continuing current operations. The second and third levels of spill were called for in other alternatives. Because of the difference in the time steps used in the models ––monthly increment for HYDROSIM, and daily increment for GASSPILL–– adjustments had to be made to ensure that average monthly spill values were the same in both models to the extent possible. Future, more detailed predictions of total dissolved gas saturation will need a more accurate definition of daily and monthly spill amounts and discharges.

It should be noted that prediction of total dissolved gas levels below Libby and Hungry Horse Dams has not been attempted for lack of appropriate modeling tools.

The plant hydraulic capacity values shown above were reduced to 0 when reservoir pool is below the following elevations (given in feet msl): 377 (Ice Harbor), 477 (Lower Monumental), 577 (Little Goose) and 673 (Lower Granite). This produced forced spill –– an operation that could occur before and after drawdown.

The natural river scenario is an exception. It is designed to release all outflow through a special bypass when the reservoir pool is lower than the indicated elevations. Spill would not occur. In this case, to avoid having to model a spill, GASSPILL had to assume that all river flows went through the powerhouses during the 2 or 4 1/2 month drawdown period.

## Table 3–4. Assumed Levels of Spill for–fish–passage (in ratio of daily average outflow) and Plant Capacity (in Kcfs)

<............... periods ...............>

| Projects | Plant Capacity (KCFS) | Spill Level | April 1–15 | April 16–30 | May 1–31 | June 1–30 | July 1–31 | Aug 1–15 | Aug 16–31 |
|---|---|---|---|---|---|---|---|---|---|
| CHJ | 219 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| WEL | 220 | 1 | 0 | .200 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | .07 | .07 | .07 | .07 | .07 | 0 | |
| | | 3 | 0 | 0 | .200 | 0 | 0 | 0 | 0 |
| RRH | 210 | 1 | 0 | .200 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 0 | .042 | .020 | 0 | 0 | 0 | 0 |
| | | 3 | 0 | 0 | .200 | 0 | 0 | 0 | 0 |
| RIS | 220 | 1 | 0 | .200 | 0 | 0 | 0 | 0 | 0 |
| | | 2 | 0 | .1 | .065 | 0 | 0 | 0 | 0 |
| | | 3 | 0 | 0 | .2 | 0 | 0 | 0 | 0 |
| WAN | 220 | 1 | 0 | 0 | .165 | .027 | .055 | .055 | |
| | | 3 | 0 | 0 | .165 | 0 | .027 | .055 | .055 |
| PRD | 187 | 1 | 0 | .188 | 9 | .026 | .053 | .053 | |
| | | 2 | 0 | 0 | .188 | 0 | .026 | .053 | .053 |
| | | 3 | 0 | 0 | .188 | 0 | .026 | .053 | .053 |
| LWG | 130 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 3 | .39 | .39 | .39 | .385 | .385 | .385 | |
| LGS | 130 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 3 | .24 | .24 | .24 | .24 | .385 | .385 | .385 |
| LMN | 130 | 1 | .013 | .200 | .200 | .215 | .215 | .215 | 0 |
| | | 2 | .023 | .350 | .350 | .350 | .24 | 0 | 0 |
| | | 3 | .305 | .305 | .305 | .405 | .405 | .405 | .405 |
| IHR | 105 | 1 | .020 | .300 | .300 | .150 | .150 | .150 | .066 |
| | | 2 | .008 | .125 | .125 | .125 | .089 | 0 | 0 |
| | | 3 | .270 | .270 | .27 | .405 | .405 | .405 | .405 |
| MCN | 232 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | |
| | | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 3 | .24 | .24 | .24 | .31 | .31 | .31 | .31 |
| JDA | 350 | 1 | 0 | 0 | .067 | .083 | .083 | .037 | |
| | | 2 | 0 | 0 | 0 | .067 | .083 | .083 | .037 |
| | | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TDA | 375 | 1 | 0 | .100 | .080 | .050 | .050 | .022 | |
| | | 2 | 0 | 0 | .100 | .080 | .050 | .050 | .022 |
| | | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| BON | 270 | 1 | .035 | .530 | .530 | .461 | .415 | .415 | .415 |
| | | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | | 3 | .5 | .5 | .5 | .51 | .43 | .43 | .43 |

The following plant capacities (in kcfs) were used:

| Draw-down (ft) | Ice Harbor | Lower Monu-mental | Little Goose | Lower Granite |
|---|---|---|---|---|
| 52 | 62,000 | 86,000 | 86,000 | 86,000 |
| 43 | 73,000 | 97,000 | 97,000 | 97,000 |
| 33 | 80,000 | 105,000 | 105,000 | 105,000 |

Prediction of total dissolved gas saturation levels in the Columbia River Salmonid Passage (CRiSP) model used by the Anadromous Fish Work Group could be carried out in the same manner as outlined above if the same calculation option was used. It should be noted, however, that the dissolved gas subroutine in CRiSP used a different set of gas entrainment and dissipation coefficients. CRiSP also relies on a different (stochastically derived) set of multipliers to derive the daily flows it needs from monthly flows generated by the HYDROSIM hydro-regulation model. Based on a quick evaluation test using 1984 and 1986 model calibration results, CRiSP–predicted total dissolved gas output was near the same order of accuracy as GASSPILL's output (See Exhibit I). CRiSP's output was usually handled internally in the model; no data on total dissolved gas was generated unless the user explicitly asked for it.

### Methodology for Sediment Modeling

This methodology  was only used to assess lower Snake River reservoir drawdown alternatives and the base case. The base case was assumed to adequately represent sediment conditions for alternatives which do not call for reservoir drawdown. These questions were addressed:

- what are reservoir trapping efficiencies?
- how would the streambed change over time?
- where would resuspended sediments resettle downstream?
- how much turbidity would be created as a result of resuspension of sediment?
- what would be the fate of contaminated sediments?

The Lower Granite Reservoir was used as a test site for assessing sediments because data was collected there during drawdown tests in 1992. The erosive actions of wind and water on reservoir banks and mud flats which were exposed during drawdown were monitored. Redistribution of sediments within the reservoir was modeled. The object was to determine the amount of sediment scoured at the upstream portion of the pool, the redeposition of the scoured sediment at downstream locations, and the amount left in suspension and discharged past the Lower Granite Dam.

Since data for many of the contaminants is very limited, 305b reports required by the Clean Water Act were consulted. Extrapolations were made from known sources of pollution; pulp mills, aluminum plants, and others. A value is assigned to these problems and reference is made to what happens to similar discharges in tributaries like the Yakima River, where better data has been collected. After initial conditions are established, the effects of changes in reservoir elevations and flows called for in each alternative were compared.

Three years were selected from the past 50 years to represent the low, medium and high flow conditions. The year 1973 was selected to be the low flow, 1959 the medium flow, and 1974 the high flow years. The worst case condition for water quality normally occur during a high flow condition for dissolved gas and sediments transport, and during a low flow condition for water temperature.

To enable estimation of long–term accumulated effects of banks and mud flats erosion , a five year simulation duration was used. The extreme high flow conditions were modeled for five years, with the first and last years using high flow data from 1974, and the middle three years using medium flow data from 1959. The extreme low flow conditions were modeled for five years, with the first and last years using low flow data from 1973, and the middle three years using medium flow data from 1959. The average flow conditions were modeled for five years using medium flow data from 1959 for each of the five years.

A daily time–step was used for the simulations because of the large changes expected in daily discharges during the drawdown and refill periods proposed for the SOR drawdown alternatives. Mean daily discharges and pool elevations were used for each time step. Only during drawdown and refill periods did the mean daily discharges and elevations change on a daily basis. Outside these periods, and for non–drawdown SOR alternatives, mean monthly discharges and elevations were fixed during each daily time step throughout a given month. March and April were special case months, because they were modeled as two 15–day time periods. In this case, mean 15–day discharges and pool elevations were assigned to each day in that period. Because the HEC–5Q model was not highly sensitive to meteorological conditions, only meteorological data from 1984 were used.

The drawdown proposals called for a pool drop of two feet per day until the pool reached the target level by April 15 of each year. This was followed by an either two or four and one half month period when the pool was allowed to fluctuate within a range of five feet below the target elevation. Then, starting at the farthest downstream reservoir, the pool would be raised as rapidly as possible while maintaining a minimum 11,000 cfs flow through all four lower Snake River projects.

To simulate those operations in HEC–6, it was assumed that the pool would remain at the bottom of the 5–foot level during the scheduled drawdown period. The actual length of the drawdown and the rate of refill of Lower Granite Pool were calculated from the flow rate and the time it would take to progressively refill each pool, starting at Ice Harbor and working upstream. During a low flow year the refill time could extend into the next water year.

A method was also developed to extrapolate sediment accumulation, loadings, transport and trapping at other dams on the lower Snake River downstream from Lower Granite Dam and the McNary and John Day Reservoirs on the Columbia (see Exhibit J). Historic accumulation of sediments was used to estimate depths and grain–size distributions of existing sediment trapped behind these dams as part of the extrapolation procedure.

The results of the sediment studies were used as input to the enhanced HEC–5Q water quality model, which has sediment transport modeling capabilities for free–flowing river reaches. HEC–5Q was used to estimate sediment trapping efficiencies of the Lower Snake River dams operating under the proposed drawdown alternatives.

The HEC–5Q model provided quantitative water quality information at one station within each major reach of the river system, and at other significant points where the greatest impacts were expected. Time series data were output from the HEC–5Q model at the John Day Dam forebay (Lower Columbia), Priest Rapids Dam forebay (Upper Columbia), Ice Harbor Dam forebay (Lower Snake), and at Lower Granite Dam forebay (high sediment impact station). The station time series output data provided value measures for alternative comparisons.

Tables and graphs were prepared to show the volume of sediment trapped upstream from and passing Lower Granite (initially) and the downstream dams (subsequently) for the range of drawdown and hydrologic conditions covered in the full–scale analysis. A snapshot analysis of sediment distribution was performed during the drawdown and for up to 20 years in the future to provide some information about erosion and sedimentation rates, including sediment aggradation and scouring. Cumulative changes over time were also added.

More details on sediment modeling are provided in Technical Exhibits J and K.

**Models:**

**Water Temperature Model**

For water temperature, the HEC–5Q based COLTEMP model was used. This model was calibrated using data for the years 1984, 1985, and 1990 which approximated lower Snake River's above average, below average, and average temperature years respectively.

The annual runoff at The Dalles for those years is 146, 114, and 121 Maf respectively. From the runoff standpoint (see Table 3-3), 1984 would rank as medium high, and 1985 and 1990 as medium low flow years at The Dalles. Sample calibration results are illustrated in Exhibit 8, with plots of the computed and observed water temperature at selected locations in the Columbia River Basin.

COLTEMP temperature model assumes that water temperature is the same within a given reservoir layer, and that there is no lateral variation between the left and right river or reservoir banks. This model has already been described in some detail in the report entitled, The Book published in August 1992. COLTEMP runs for full-scale analysis started earlier than the July 1 date used during screening so that all reservoirs would initially be in a fully mixed condition. Also, in the full-scale analysis, Libby and Hungry Horse reservoirs were separately modeled.

The enhanced HEC-5Q model simulates the following water quality parameters (those available in the screening version are shown with an asterisk):

water temperature *
coliform bacteria *
carbonaceous BOD *
ammonia nitrogen *
nitrate nitrogen *
total dissolved phosphorous *
phytoplankton *
pH
chlorides
alkalinity
total inorganic carbon
dioxins or dibenzofurans
organic and/or inorganic particulates

Results of model calibration for these parameters are also provided in Technical Exhibit H. Because there were not enough field data to fully calibrate the model, the enhanced tool was only used to provide a rough estimate of relative changes in these parameters attributable to different flow regimes. The enhancement was based on scientifically sound algorithms and helped the analyst to better understand the behavior of the prototype.

**Total Dissolved Gas Model**

GASSPILL is a full-scale, one-dimension model covering the Columbia and Snake Rivers from Grand Coulee and Lower Granite Dams to Bonneville. It assumes no lateral variation between the two river banks; and no depth variation in the saturation level. This model provided a more complete simulation than the simpler, spreadsheet-type empirical model used in the screening.

GASSPILL operates on a daily time step from April 1 through August 30. It was calibrated using daily data for 1984 and 1986, the two most recent wet years in the Columbia River basin. Calibration results were considered reasonable by modelers and analysts, given the complexity of the actual physical process involved and its variability in space and in time. In modeling System Operation Review alternatives, contribution from Canadian and upper Snake River projects had to be assumed. Sample calibration results are provided in sample plots provided in Technical Exhibit I. Because dissolved gas saturation is a highly variable water quality parameter, both in time and in space, a detailed modeling of this parameter is not as easy as water temperature modeling. Efforts are currently under way under the Dissolved Gas Abatement Study to improve existing models and developing better models of dissolved gas supersaturation.

**Sediment Model**

The Corps of Engineers Scour and Deposition in Rivers and Reservoirs Model, HEC-6, has been used for the Lower Granite Reservoir since 1984. This is an one dimensional, steady flow, mathematical sediment transport model that assumes a uniform velocity distribution and uniform sediment deposition across the entire cross-section of the reservoir.

HEC-6 does not reproduce observed deposition or compute deposition for specific sites, it estimates long-term patterns of reservoir sediment profiles. Using a time sequence of flows along with data for the inflowing sediment load, the model routes the sediments through a river reach for various operating pool elevations. Depending on the gate settings and the particle sizes, the river upstream from the dam could be either depositing sediments or transporting them through the system.

The original HEC–6 model for Lower Granite Reservoir was calibrated for reservoir operations within normal operating range, between 733 and 738 feet msl, and operated almost exclusively as an aggrading model. It extended from river mile 7.85 on the Clearwater and river mile 148.83 on the Snake River, downstream to Lower Granite Dam (river mile 107.43).

The model was calibrated to match observed sediment accumulation and distribution as calculated from sediment range resurveys of the reservoir starting with the pool raise in the spring of 1975. It contained a gravel and cobble bed for a starting channel bed gradation, and the incoming sediment accumulated over this bed. Sediment load curves for suspended and bed load entering the upper boundary of the model were based on actual measurements made between 1972 and 1978 at Anatone on the Snake River and Spaulding on the Clearwater River.

In order to use the model for erosion studies, the bed gradation subroutine was completely recoded. Initial bed gradations were based on laboratory gradation tests of sediment samples from the reservoir bed averaged over approximately five mile reaches of the pool. To match calibration results, all silt sizes for both the bed and the upstream supply were expressed as coarse silt (0.031 to 0.0625 mm).

Because the model assumed that sediment data and sediment transport, and hydraulic parameters were varied only in the direction of the flow (no lateral and no depth variation), grain size adjustments were necessary to refine model calibration to conditions observed during the 1992 drawdown test. At some cross–sections in the vicinity of the Clearwater/Snake River confluence, it was necessary to set limits to the width of the low flow channel to duplicate the 1992 event. More details are provided in Technical Exhibit G. Mathematical models of water chemistry, suspended sediment and primary productivity have a fairly high degree of uncertainty. It is, therefore, important that care be given to developing hypotheses and designing studies to test these hypotheses. The existing models provide the initial basis for such hypotheses as well as mechanisms for appropriate monitoring systems.

### 3.3.2 Performance indices

In order to provide a common denominator for the performance of the various alternatives, several quantitative indices were used to reflect penalties for not meeting a given target. Performance indices were calculated for all years simulated to cover the average and worst cases conditions at all the locations included in the models. Most significant locations are Priest Rapids, Lower Granite, and The Dalles for water temperature; and Priest Rapids, Ice Harbor, and The Dalles for total dissolved gas.

As defined, performance indices reflect the extent to which an alternative fails to meet known desired conditions and/or existing standard. They may also be referred to as penalties. Average values are arithmetic means for all years involved; high/low values refer to the highest/lowest values predicted in any one of those years; and individual year values are specific to the years indicated.

For water temperature, the performance index was defined as the number of days the predicted water temperature for a given alternative exceeds the tolerance temperature for anadromous fish during the April through September period (17.2 degrees C or 63 degrees F). This temperature threshold was selected instead of the standard, 68 degrees, because fish can survive in 68 degree water but they need 63 degree temperature to function biologically.

For total dissolved gas saturation, the performance index was defined as the total number of days during the April–August period the standard saturation level of 110 percent is exceeded. This level, however, is not lethal for fish species whose normal habitat is in water deep enough to provide adequate hydrostatic pressure compensation. Because of this, two higher levels of saturation levels (120 and 130 percent) were also used.

For sediments, performance indices were defined as total sediment transported in the first and fifth year of operation. These indices provided a picture of the dynamics of the sediment transport process, which was expected to be very active at first and to gradually reach equilibrium state after a few years time. The value measure was the frequency of water quality standard exceedences, computed from the HEC–5Q model output.

### 3.3.3 Full-scale Analysis Results

Water temperature and total dissolved gas saturation prediction results are given in Technical Exhibit D. Graphs are also provided showing: 1) the daily variations of the water quality parameter involved; and 2) the number of days exceeding given threshold values (performance indices).

Graphic displays in the latter group are of two types. The first shows the number of days thresholds are exceeded for each alternative at all locations modeled; it provides a graphical comparison of the performances of all alternatives at all sites. The second shows the high, average, and low numbers of days exceeded for all alternatives at one selected location. This graphic provides the range of values to be expected at that one site under various regulation scenarios.

Sample plots showing predicted daily water temperature and total dissolved gas saturation and the number of days exceeding the given treshold are provided in Figures 3–5, 3–6, 3–7, and 3–8.

For sediment transport, HEC–6 model runs were only made for alternatives involving lower Snake River reservoir drawdown and the base case. Sediment transport results include the predicted volume of sediment eroded at the end of the first and fifth years of operation in each case under average flow conditions. More detailed information is provided in Technical Exhibit G, and a sample plot of predicted sediment transport is shown in Figure 3–9.

For selected water quality parameters such as algae, ammonia, DDT, lead, and silt, frequency analysis results in relation to selected treshold values are provided in Technical Exhibit J. A graphic post–processing program was used to plot an instantaneous longitudinal profile of simulated water quality parameter concentrations within the water column and bed sediment. The profiles were plotted from Bonneville Dam, upstream to Grand Coulee, Brownlee, or Dworshak Dams. The profile data were output on the fifteenth day of each month. Profiles for a maximum of three days could be plotting on one graph. Accumulated silt sediments were plotted along the Columbia River for December of each of the five years in a simulation to show the deposition of sediment load below the confluence of the Snake River.

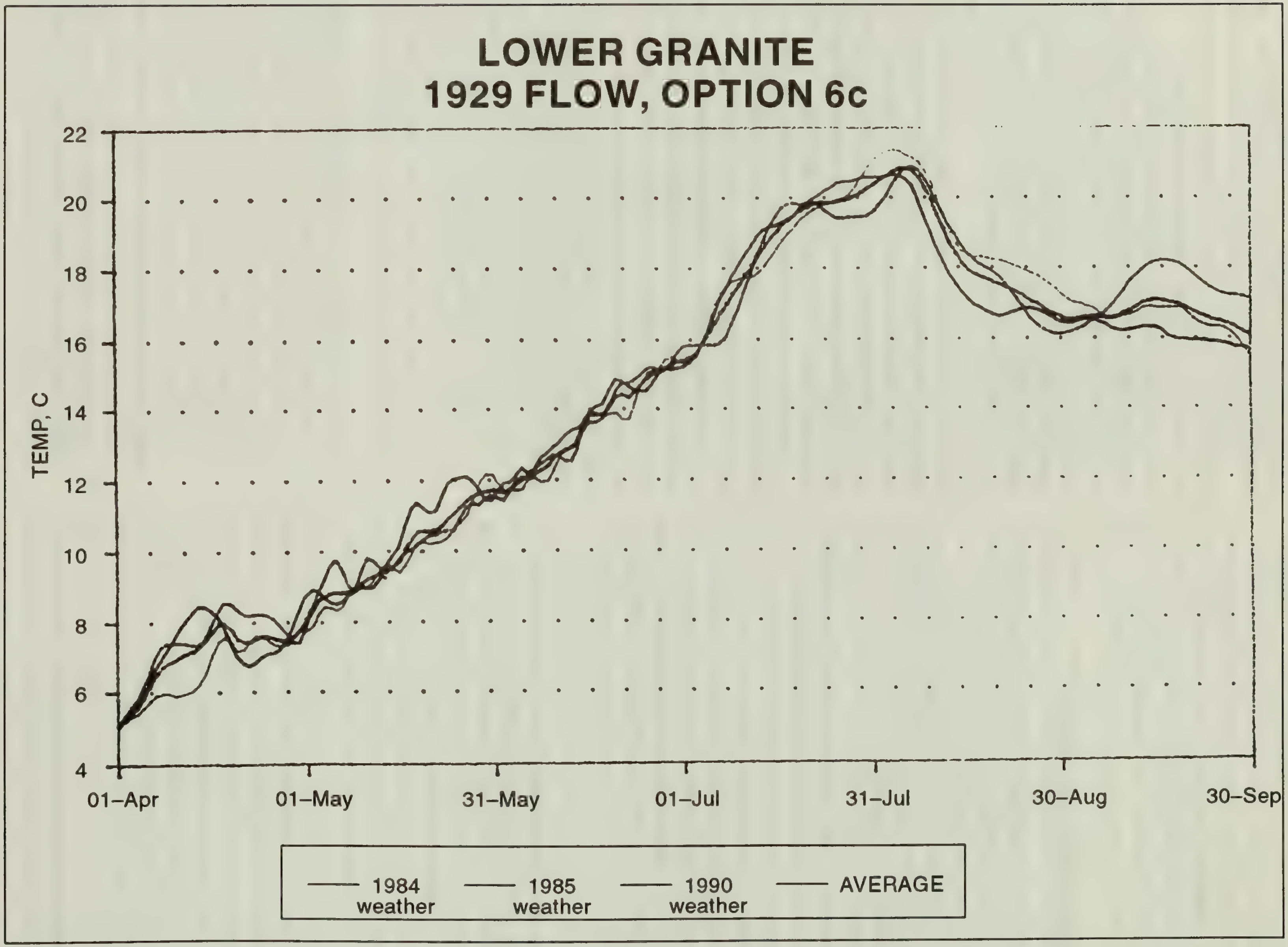


Figure 3–5. Sample Plot of Predicted Daily Water Temperature

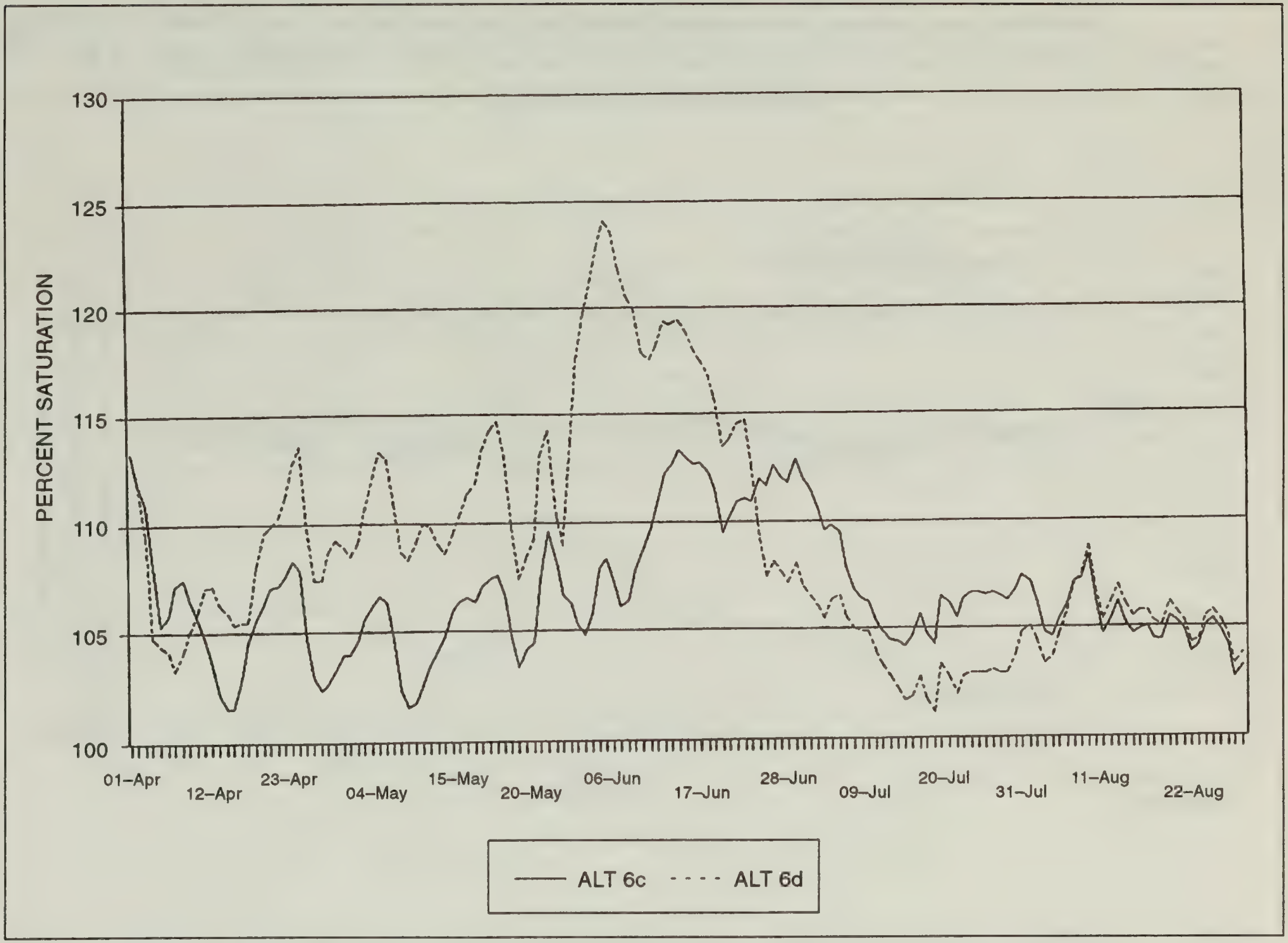


**Figure 3–6.** **Sample Plot of Predicted Total Dissolved Gas Saturation Ice Harbor Forebay, 1938 (average runoff)**

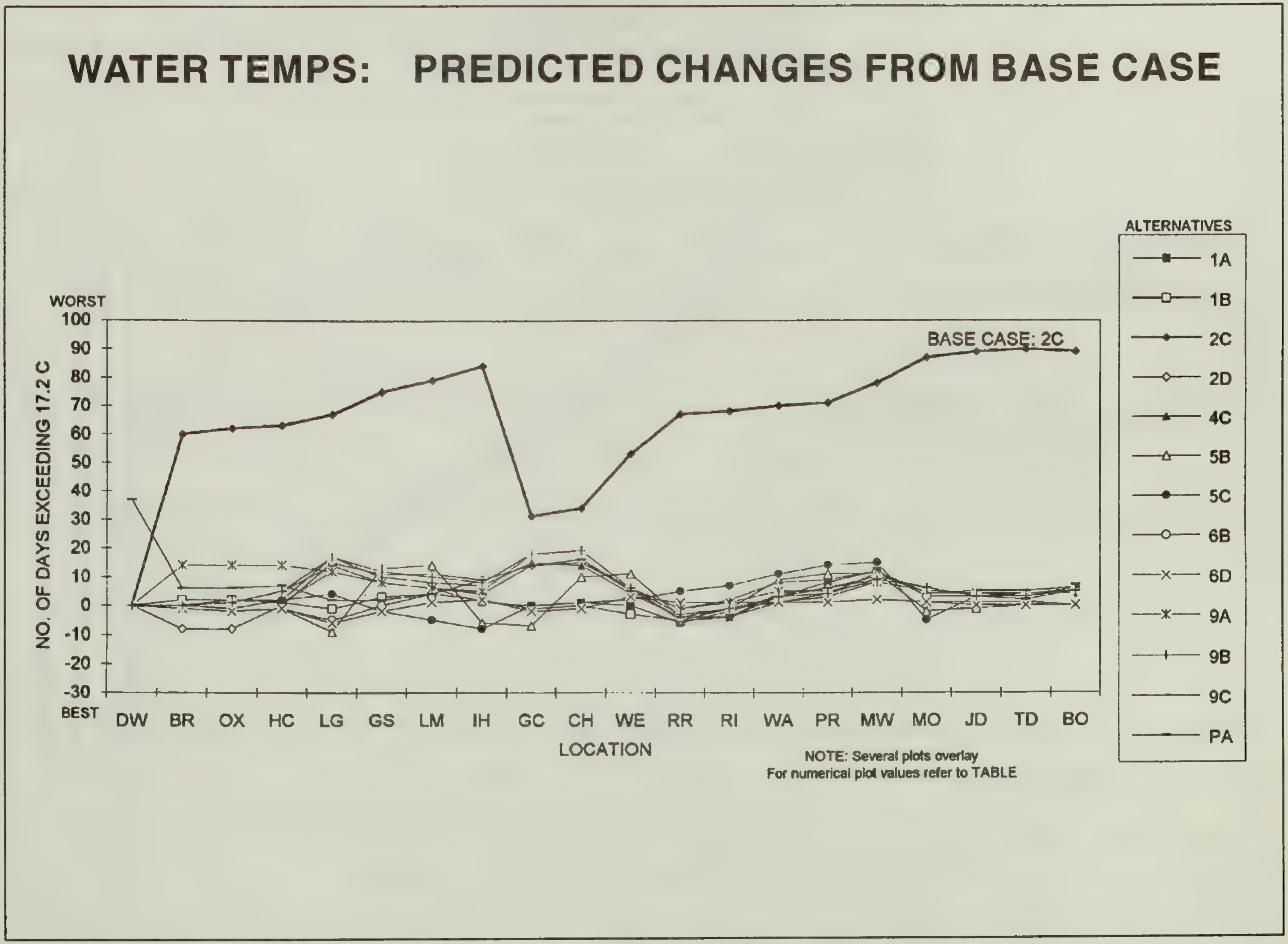


Figure 3–7. Sample Plot of Number of Days Exceeding Temperature Treshold at All Locations

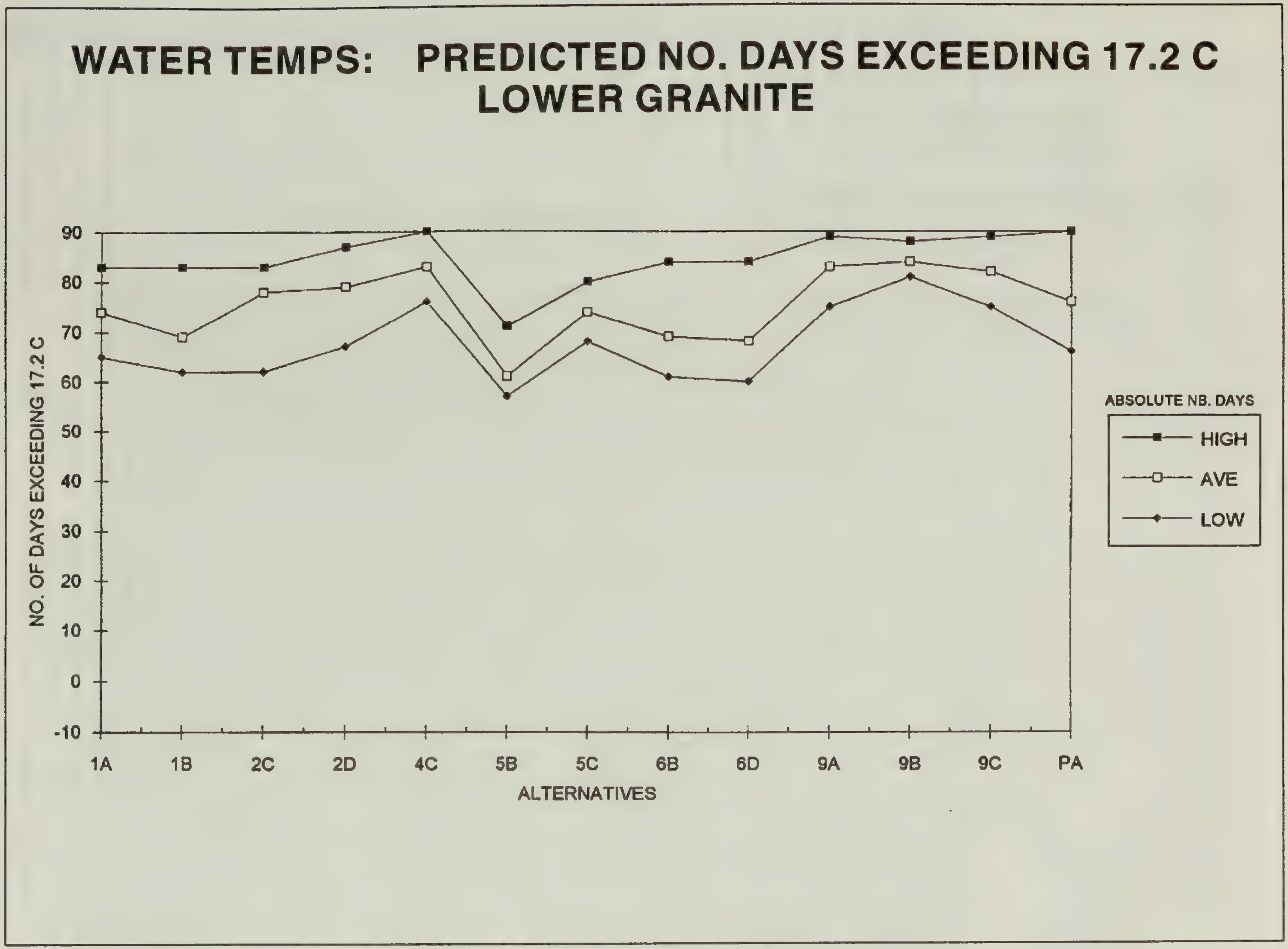


Figure 3–8. Sample Plot of Number of Days Exceeding Treshold at One Station (Lower Granite Dam)

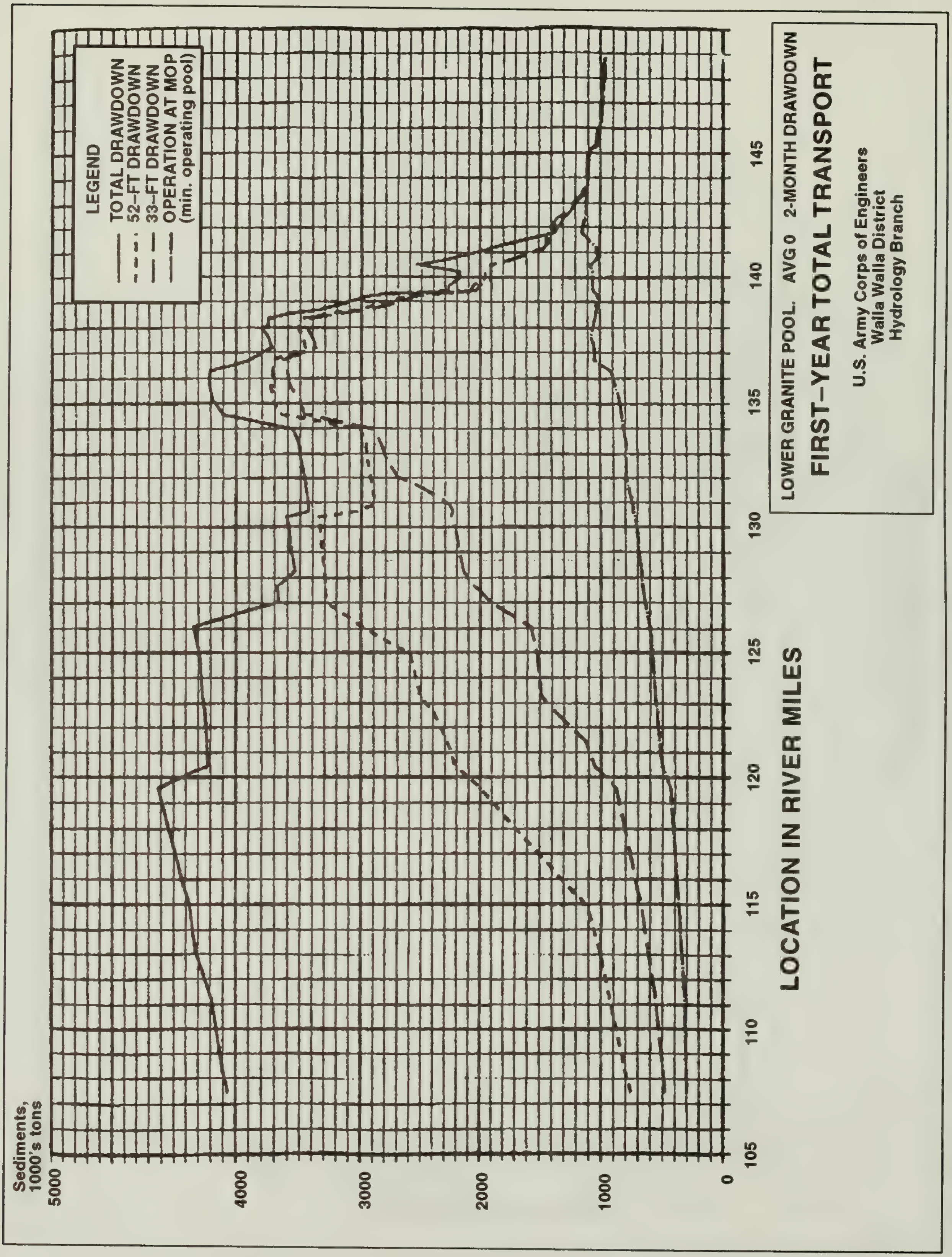


**Figure 3–9.** Sample Plot of Predicted Sediment Transport at Lower Granite Reservoir

# CHAPTER 4

# ALTERNATIVES AND THEIR IMPACTS ON WATER QUALITY

## 4.1 GENERAL DESCRIPTION OF ALTERNATIVES

Seven alternative System Operating Strategies (SOS) were considered in the Draft EIS. Each of the 7 SOSs contained several options, bringing the total number of alternatives considered to 21. This Final EIS also evaluates 7 operating strategies, with a total of 13 alternatives now under consideration when accounting for options. Section 4.1 of this chapter describes the 13 alternatives and provides the rationale for including these alternatives in the Final EIS. Operating elements for each alternative are summarized in Table 4–1. Later sections of this chapter describe the effects of these alternatives on water quality. Figure 4–1, shown after Section 4.1, shows pool elevations at Dworshak Reservoir; and Figure 4–2, pool elevations at Lower Granite Reservoir. They provide an appreciation for the range of reservoir fluctuations called for in the various alternatives in a year like 1929. Figures 4–3, 4–4, and 4–5, shown after Section 4.1, show the simulated 1929 outflow at Priest Rapids, Lower Granite, and The Dalles Dams respectively.

The 13 final alternatives represent the results of the third analysis and review phase completed since SOR began. In 1992, the agencies completed an initial effort, known as "Screening" which identified 90 possible alternatives. Simulated operation for each alternative was completed for five water year conditions ranging from dry to wet years, impacts to each river use area were estimated using simplified analysis techniques, and the results were compared to develop 10 "candidate SOSs." The candidate SOSs were the subject of a series of public meetings held throughout the Pacific Northwest in September 1992. After reviewing public comment on the candidate strategies, the SOR agencies further reduced the number of SOSs to seven. These seven SOSs were evaluated in more detail by performing 50–year hydroregulation model simulations and by determining river use impacts. The impact analysis was completed by the SOR workgroups. Each SOS had several options so, in total, 21 alternatives were evaluated and compared. The results were presented in the Draft EIS, published in July, 1994. As was done after Screening, broad public review and comment was sought on the Draft EIS. A series of nine public meetings was held in September and October 1994, and a formal comment period on the Draft EIS was held open for over 4 1/2 months. Following this last process, the SOR agencies have again reviewed the list of alternatives and have selected 13 alternatives for consideration and presentation in the Final EIS.

Six options for the alternatives remain unchanged from the specific options considered in the Draft EIS. One option (SOS 4c) is a revision to a previously considered alternative, and the rest represent replacement or new alternatives. The basic categories of SOSs and the numbering convention remains the same as was used in the Draft EIS. However, because some of the alternatives have been dropped, the final SOSs are not numbered consecutively. There is one new SOS category, Settlement Discussion Alternatives, which is labeled SOS 9 (see Section 4.1.6 for discussion).

The 13 alternatives have been evaluated through the use of a computerized model known as HYDROSIM. Developed by BPA, HYDROSIM is a hydroregulation model that simulates the coordinated operation of all projects in the Columbia River system. It is a monthly model with 14 total time periods. April and August are split into two periods each, because major changes can occur in streamflows in the first and second half of each of these months. The model is based on hydrologic data for a 50–year period of record from 1928 through 1978. For a given set of operating rule inputs and other

## Table 4–1. SOS Alternative–1

### Summary of SOS

| SOS 1<br>Pre-ESA Operation | SOS 2<br>Current Operations | SOS 4<br>Stable Storage Project Operation |
|---|---|---|
| SOS 1 represents system operations before changes were made as a result of the ESA listing of three Snake River salmon stocks. SOS 1a represents operations from 1983 through the 1990–91 operating year, influenced by Northwest Power Act; SOS 1b represents how the system would operate without the Water Budget and related operations to benefit anadromous fish. Short-term operations would be conducted to meet power demands while satisfying nonpower requirements. | SOS 2 reflects operation of the system with interim flow improvement measures in response to the ESA salmon listings. It is consistent with the 1992–93 operations described in the Corps' 1993 Interim Columbia and Snake River Flow Improvement Measures Supplemental EIS. SOS 2c represents the operating decision made as a result of the 1993 Supplemental EIS and is the no action alternative for the SOS. Relative to SOS 1a, primary changes are additional flow augmentation in the Columbia and Snake Rivers and modified pool levels at lower Snake and John Day reservoirs during juvenile salmon migration. SOS 2d represents operations of the 1994-98 Biological Opinion issued by NMFS, with additional flow aumentation measures compared to SOS 2c. | SOS 4 would coordinate operation of storage reservoirs to benefit recreation, resident fish, wildlife, and anadromous fish, while minimizing impacts to power and flood control. Reservoirs would be managed to specific elevations on a monthly basis; they would be kept full longer, while still providing spring flows for fish and space for flood control. The goal is to minimize reservoir fluctuations while moving closer to natural flow conditions. SOS 4c attempts to accommodate anadromous fish needs by shaping mainstem flows to benefit migrations and would modify the flood control operations at Grand Coulee. |

### Actions by Project

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **LIBBY** | **SOS 1a**<br>Normal 1983–1991 storage project operations | **SOS 2c**<br>Operate on system proportional draft as in SOS 1a | **SOS 4c**<br>• Meet specific elevation targets as indicated by Integrated Rule Curves (IRCs); IRCs are based on storage content at the end of the previous year, determination of the appropriate year within the critical period, and runoff forecasts beginning in January<br>• IRCs seek to keep reservoir full (2,459 feet) June-Sept; minimum annual elevation ranges from 2,399 to 2,327 feet, depending on critical year determination<br>• Meet variable sturgeon flow targets at Bonners Ferry during May 25-August 16 period; flow targets peak as high as 35 kcfs in the wettest years |
| | **SOS 1b**<br>• Minimum project flow 3 kcfs<br>• No refill targets<br>• Summer draft limit of 5–10 feet | **SOS 2d**<br>• Provide flow augmentation for salmon and sturgeon when Jan. to July forecast is greater than 6.5 MAF<br>• Meet sturgeon flows of 15, 20, and 12.5 kcfs in May, June, and July, respectively, in at least 3 out of 10 years | |

KAF = 1.234 million cubic meters

MAF = 1.234 billion cubic meters

## Table 4–1. SOS Alternative–1

| SOS 5 Natural River Operation | SOS 6 Fixed Drawdown | SOS 9 Settlement Discussion Alternatives | SOS PA |
|---|---|---|---|
| SOS 5 would aid juvenile salmon by increasing river velocity. The four lower Snake River projects would have new outlets installed, allowing the reservoirs to be drawn down to near the original river elevation. The "natural river" operation would be done for 4 1/2 months in SOS 5b and year-round in SOS 5c. John Day would also be operated at MOP for 4 months, and flow augmentation measures on the Columbia River portion of the basin would continue as in SOS 2c. | SOS 6 involves drawing down lower Snake River projects to fixed elevations below MOP to aid anadromous fish. SOS 6b provides for fixed drawdowns for all four lower Snake projects for 4 1/2 months; SOS 6d draws down Lower Granite only for 4 1/2 months. John Day would also be operated at MOP for 4 months, and flow augmentation measures on the Columbia River portion of the basin would continue as in SOS 2c. | SOS 9 represents operations suggested by the USFWS, NMFS, the state fisheries agencies, Native American tribes, and the Federal operating agencies during the settlement discussions in response to the *IDFG v. NMFS* court proceedings. This alternative has three options, SOSs 9a, 9b, and 9c, that represent different scenarios to provide increased river velocities for anadromous fish by establishing flow targets during migration and to carry out other actions to benefit ESA-listed species. The three options are termed the Detailed Fishery Operating Plan (9a), Adoptive Management (9b), and the Balanced Impacts Operation (9c). | SOS PA represents the operation recommended by NMFS and the USFWS Biological Opinions issued March 1, 1995. This SOS supports recovery of ESA-listed species by storing water during the fall and winter to meet spring and summer flow targets, and protects other resources by setting summer draft limits to manage negative effects, by providing flood protection, and by providing for reasonable power generation. |

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b**<br>Operate on system proportional draft as in SOS 1a | **SOS 6b**<br>Operate on system proportional draft as in SOS 1a | **SOS 9a**<br>• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period<br>• Provide sturgeon flow releases April-Aug. to achieve up to 35 kcfs at Bonner's Ferry with appropriate ramp up and ramp down rates | **SOS PA**<br>• Operate on minimum flow up to flood control rule curves beginning in Jan., except during flow augmentation period<br>• Strive to achieve flood control elevations in Dec. in all years and by April 15 in 75 percent of years<br>• Provide sturgeon flows of 25 kcfs 42 days in June and July<br>• Provide sufficient flows to achieve 11 kcfs flow at Bonner's Ferry for 21 days after maximum flow period<br>• Draft to meet flow targets, to a minimum end of Aug. elevation of 2,439 feet, unless deeper drafts needed to meet sturgeon flows |
| **SOS 5c**<br>Operate on system proportional draft as in SOS 1a | **SOS 6d**<br>Operate on system proportional draft as in SOS 1a | **SOS 9b**<br>• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation<br>• Provide sturgeon flow releases similar to SOS 2d<br>• Can draft to elevation 2,435 by end of July to meet flow targets | |
| | | **SOS 9c**<br>• Operate to the Integrated Rule Curves and provide sturgeon flow releases as in SOS 4c | |

1 kcfs = 28 cms

1 ft = 0.3048 meter

## Table 4–1. SOS Alternative–2

### Actions by Project

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **HUNGRY HORSE** | **SOS 1a**<br>Normal 1983–1991 storage project operations | **SOS 2c**<br>Operate on system proportional draft as in SOS 1a | **SOS 4c**<br>• Meet specific elevation targets as indicated by Integrated Rule Curves (IRCs), similar to operation for Libby<br>• IRCs seek to keep reservoir full (3,560 feet) June-Sept.; minimum annual elevation ranges from 3,520 to 3,450 feet, depending on critical year |
| | **SOS 1b**<br>• No maximum flow restriction from mid-Oct. to mid-Nov.<br>• No draft limit; no refill target | **SOS 2d**<br>Operate on system proportional draft as in SOS 1a | |

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **ALBENI FALLS** | **SOS 1a**<br>Normal 1983–1991 storage project operations | **SOS 2c**<br>Operate on system proportional draft as in SOS 1a | **SOS 4c**<br>Elevation targets established for each month, generally 2,056 feet Oct.–March, 2,058 to 2,062.5 feet April–May, 2,062.5 feet (full) June, 2,060 feet July–Sept. (but higher if runoff high); Oct.–March drawdown to 2,051 feet every 6th year |
| | **SOS 1b**<br>No refill target | **SOS 2d**<br>Operate on system proportional draft as in SOS 1a | |

KAF = 1.234 million cubic meters

MAF = 1.234 billion cubic meters

## Table 4–1. SOS Alternative–2

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b**<br>Operate on system proportional draft as in SOS 1a | **SOS 6b**<br>Operate on system proportional draft as in SOS 1a | **SOS 9a**<br>• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period | **SOS PA**<br>• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period<br>• Strive to achieve flood control elevations by April 15 in 75 percent of the years<br>• Draft to meet flow targets, to a minimum end-of-August elevation of 3,540 feet |
| **SOS 5c**<br>Operate on system proportional draft as in SOS 1a | **SOS 6d**<br>Operate on system proportional draft as in SOS 1a | **SOS 9b**<br>• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation<br>• Can draft to meet flow targets, to a minimum end-of-July elevation of 3,535 feet | |
| | | **SOS 9c**<br>• Operate to the Integrated Rule Curves as in SOS 4c | |

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b**<br>Operate on system proportional draft as in SOS 1a | **SOS 6b**<br>Operate on system proportional draft as in SOS 1a | **SOS 9a**<br>Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period | **SOS PA**<br>• Operate to flood control elevations by April 15 in 90 percent of the years<br>• Operate to help meet flow targets, but do not draft below full pool through Aug. |
| **SOS 5c**<br>Operate on system proportional draft as in SOS 1a | **SOS 6d**<br>Operate on system proportional draft as in SOS 1a | **SOS 9b**<br>• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period<br>• Can draft to meet target flows, to a minimum end-of-July elevation of 2,060 feet | |
| | | **SOS 9c**<br>• Elevation targets established for each month, generally no lower than 2,056 feet Dec.—April, no lower than 2,057 feet end of May, full (2,062.5 feet) June—Aug., 2,056 feet Sept.—Nov. | |

1 kcfs = 28 cms

1 ft = 0.3048 meter

## Table 4–1. SOS Alternative–3
### Actions by Project

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **GRAND COULEE** | **SOS 1a**<br>• Operate to meet Water Budget target flows of 134 kcfs at Priest Rapids in May[1]<br>• Meet minimum elevation of 1,240 feet in May<br>**SOS 1b**<br>• No refill target of 1,240 feet in May<br>• Maintain 1,285 feet June–Sept.; minimum 1,220 feet rest of year<br>• No May–June flow target | **SOS 2c**<br>• Storage of water for flow augmentation from January through April<br>• Supplemental releases (in conjunction with upstream projects) to provide up to 3 MAF additional (above Water Budget) flow augmentation in May and June, based on sliding scale for runoff forecasts<br>• System flood control space shifted from Brownlee, Dworshak<br>**SOS 2d**<br>• Contribute, in conjunction with upstream storage projects, up to 4 MAF for additional flow augmentation<br>• Operate in summer to provide flow augmentation water and meet downstream flow targets, but draft no lower than 1,280 feet | **SOS 4c**<br>• Operate to end-of-month elevation targets, as follows:<br>1,288 Sept.-Nov<br>1,287 Dec.<br>1,270 Jan.<br>1,260 Feb.<br>1,270 Mar.<br>1,272 Apr. 15<br>1,275 Apr. 30<br>1,280 May<br>1,288 Jun.-Aug.<br>• Meet flood control rule curves only when Jan.-June runoff forecast exceeds 68 MAF |

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **PRIEST RAPIDS** | **SOS 1a**<br>• Meet May-June flow targets[1]<br>• Maintain minimum flows to meet Vernita Bar Agreement[2]<br>**SOS 1b**<br>• No May flow target<br>• Meet Vernita Bar Agreement | **SOS 2c**<br>Operate as in SOS 1a<br>**SOS 2d**<br>Operate as in SOS 1a | **SOS 4c**<br>Operate as in SOS 1a |

[1] Flow targets are weekly averages with weekend and holiday flows no less than 80 percent of flows over previous 5 days.

[2] 55 kcfs during heavy load hours October 15 to November 30; minimum instantaneous flow 70 kcfs December to April

KAF = 1.234 million cubic meters MAF = 1.234 billion cubic meters

## Table 4–1. SOS Alternative–3

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b**<br>Operate on system proportional draft and provide flow augmentation as in SOS 2c | **SOS 6b**<br>Operate on system proportional draft and provide flow augmentation as in SOS 2c | **SOS 9a**<br>• Operate to meet flood control requirements and Vernita Bar agreement<br>• Provide flow augmentation releases to help meet targets at The Dalles of 220-300 kcfs April 16-June 15, 200 kcfs June 16-July 31, and 160 kcfs Aug. 1-Aug.31, based on appropriate critical year determination<br>• In above average runoff years, provide 40% of the additional runoff volume as flow augmentation | **SOS PA**<br>• Operate to achieve flood control elevations by April 15 in 85% of years<br>• Draft to meet flow targets, down to minimum end-of-Aug. elevation of 1,280 feet<br>• Provide flow augmentation releases to meet Columbia River flow targets at McNary of 220-260 kcfs April 20-June 30, based on runoff forecast, and 200 kcfs July-Aug. |
| **SOS 5c**<br>Operate on system proportional draft and provide flow augmentation as in SOS 2c | **SOS 6d**<br>Operate on system proportional draft and provide flow augmentation as in SOS 2c | **SOS 9b**<br>• Operate on minimum flow up to flood control rule curves year-round, except during flow augmentation period<br>• Can draft to meet flow targets, bounded by SOS 9a and 9c targets, to a minimum end-of-July elevation of 1,265 feet | |
| | | **SOS 9c**<br>• Operate to meet McNary flow targets of 200 kcfs April 16-June 30 and 160 kcfs in July<br>• Can draft to meet flow targets, to a minimum end-of-July elevation of 1,280 feet<br>• Contribute up to 4 MAF for additional flow augmentation, based on sliding scale for runoff forecasts, in conjunction with other upstream projects<br>• System flood control shifted to this project | |

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b**<br>Operate as in SOS 1a | **SOS 6b**<br>Operate as in SOS 1a | **SOS 9a**<br>Operate as in SOS 1a | **SOS PA**<br>Operate as in SOS 1a |
| **SOS 5c**<br>Operate as in SOS 1a | **SOS 6d**<br>Operate as in SOS 1a | **SOS 9b**<br>Operate as in SOS 1a | |
| | | **SOS 9c**<br>Operate as in SOS 1a | |

1 kcfs = 28 cms 1 ft = 0.3048 meter

## Table 4–1. SOS Alternative–4

### Actions by Project

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **SNAKE RIVER ABOVE BROWNLEE** | **SOS 1a**<br>Normal 1990—91 operations; no Water Budget flows | **SOS 2c**<br>Release up to 427 KAF (190 KAF April 16—June 15; 137 KAF Aug.; 100 KAF Sept.) for flow augmentation | **SOS 4c**<br>Same as SOS 1a |
| | **SOS 1b**<br>Same as SOS 1a | **SOS 2d**<br>• Release up to 427 KAF, as in SOS 2c<br>• Release additional water obtained by purchase or other means and shaped per Reclamation releases and Brownlee draft requirements; simulation assumed 927 KAF available | |

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **BROWNLEE** | **SOS 1a**<br>• Draft as needed (up to 110 KAF in May) for Water Budget, based on target flows of 85 kcfs at Lower Granite<br>• Operate per FERC license<br>• Provide system flood control storage space | **SOS 2c**<br>Same as SOS 1a except for additional flow augmentation as follows:<br>• Draft up to 137 KAF in July, but not drafting below 2,067 feet; refill from the Snake River above Brownlee in August<br>• Draft up to 100 KAF in Sept.<br>• Shift system flood control to Grand Coulee<br>• Provide 9 kcfs or less in November; fill project by end of month<br>• Maintain November monthly average flow December through April | **SOS 4c**<br>Same as SOS 1a except slightly different flood control rule curves |
| | **SOS 1b**<br>• No maximum flow restriction from mid-Oct. to mid-Nov.<br>• No draft limit; no refill target | **SOS 2d**<br>Same as SOS 2c, plus pass additional flow augmentation releases from upstream projects | |

KAF = 1.234 million cubic meters

MAF = 1.234 billion cubic meters

## Table 4–1. SOS Alternative–4

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b** | **SOS 6b** | **SOS 9a** | **SOS PA** |
| Same as SOS 1a | Same as SOS 1a | Provide up to 1.927 MAF through Brownlee for flow augmentation, as determined by Reclamation | Provide 427 KAF through Brownlee for flow augmentation, as determined by Reclamation |
| **SOS 5c** | **SOS 6d** | **SOS 9b** | |
| Same as SOS 1a | Same as SOS 1a | Provide up to 927 KAF through Brownlee as determined by Reclamation | |
| | | **SOS 9c** | |
| | | Provide up to 927 KAF through Brownlee as determined by Reclamation | |

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b** | **SOS 6b** | **SOS 9a** | **SOS PA** |
| Same as SOS 4c | Same as SOS 4c | • Draft up to 110 KAF in May, 137 KAF in July, 140 KAF in Aug., 100 KAF in Sept. for flow augmentation<br>• Shift system flood control to Grand Coulee | Draft to elevation 2,069 feet in May, 2,067 feet in July, and 2,059 feet in Sept., passing inflow after May and July drafts |
| **SOS 5c** | **SOS 6d** | **SOS 9b** | |
| Same as SOS 4c | Same as SOS 4c | • Draft up to 190 KAF April-May, 137 KAF in July, 100 KAF in Sept. for flow augmentation<br>• Shift system flood control to Grand Coulee<br>• Provide an additional 110 KAF in May if elevation is above 2,068 feet and 110 KAF in Sept. if elevation is above 2,043.3 feet | |
| | | **SOS 9c** | |
| | | Same as SOS 9b | |

1 kcfs = 28 cms

1 ft = 0.3048 meter

## Table 4–1. SOS Alternative–5

**Actions by Project**

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **DWORSHAK** | **SOS 1a**<br>• Draft up to 600 KAF in May to meet Water Budget target flows of 85 kcfs at Lower Granite<br>• Provide system flood control storage space<br>**SOS 1b**<br>• Meet minimum project flows (2 kcfs, except for 1 kcfs in August); summer draft limits; maximum discharge requirement Oct. to Nov. (1.3 kcfs plus inflow)<br>• No Water Budget releases | **SOS 2c**<br>Same as SOS 1a, plus the following supplemental releases:<br>• 900 KAF or more from April 16 to June 15, depending on runoff forecast at Lower Granite<br>• Up to 470 KAF above 1.2 kcfs minimum release from June 16 to Aug. 31<br>• Maintain 1.2 kcfs discharge from Oct. through April, unless higher required<br>• Shift system flood control to Grand Coulee April–July if runoff forecasts at Dworshak are 3.0 MAF or less<br>**SOS 2d**<br>• Operate on 1.2 kcfs minimum discharge up to flood control rule curve, except when providing flow augmentation (April 10 to July 31)<br>• Provide flow augmentation of 1.0 MAF plus 1.2 kcfs minimum discharge, or 927 KAF and 1.2 kcfs, from April 10-June 20, based on runoff forecasts, to meet Lower Granite flow target of 85 kcfs<br>• Provide 470 KAF from June 21 to July 31 to meet Lower Granite flow target of 50 kcfs<br>• Draft to 1,520 feet after volume is expended, if Lower Granite flow target is not met; if volume is not expended, draft below 1,520 feet until volume is expended | **SOS 4c**<br>Elevation targets established for each month: 1,599 feet Sept.-Oct.; flood control rule curves Nov.-April; 1,595 feet May; 1,599 feet June-Aug.; |

KAF = 1.234 million cubic meters

MAF = 1.234 billion cubic meters

## Table 4–1. SOS Alternative–5

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b**<br>• Operate to local flood control rule curve<br>• No proportional draft for power<br>• Shift system flood control to lower Snake projects<br>• Provide Water Budget flow augmentation as in SOS 1a<br>• Draft to refill lower Snake projects if natural inflow is inadequate | **SOS 6b**<br>Same as SOS 5b | **SOS 9a**<br>• Remove from proportional draft for power<br>• Operate to local flood control rule curves, with system flood control shifted to Grand Coulee<br>• Maintain flow at 1.2 kcfs minimum discharge, except for flood control or flow augmentation discharges<br>• Operate to meet Lower Granite flow targets (at spillway crest) of 74 kcfs April 16-June 30, 45 kcfs July, 32 kcfs August | **SOS PA**<br>• Operate on minimum flow-up to flood control rule curve year-round, except during flow augmentation period<br>• Draft to meet flow targets, down to min. end-of-Aug. elevation of 1,520 feet<br>• Sliding-scale Snake River flow targets at Lower Granite of 85 to 100 kcfs April 10-June 20 and 50 to 55 kcfs June 21-Aug. 31, based on runoff forecasts |
| **SOS 5c**<br>• Operate to flood control during spring<br>• Refill in June or July and maintain through August<br>• Draft for power production during fall | **SOS 6d**<br>Same as SOS 5b | **SOS 9b**<br>• Similar to SOS 9a, except operate to meet flow targets at Lower Granite ranging from 85 to 140 kcfs April 16-June 30 and 50-55 kcfs in July<br>• Can draft to meet flow targets to a min. end-of-July elevation of 1,490 feet | |
| | | **SOS 9c**<br>• Similar to SOS 9a, except operate to meet Lower Granite flow target (at spillway crest) of 63 kcfs April-June<br>• Can draft to meet flow targets to a min. end-of-July elevation of 1,520 feet | |

1 kcfs = 28 cms

1 ft = 0.3048 meter

## Table 4–1. SOS Alternative–6
### Actions by Project

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **LOWER SNAKE** | **SOS 1a**<br>• Normal operations at 4 lower Snake River projects (within 3 to 5 feet of full pool, daily and weekly fluctuations)<br>• Provide maximum peaking capacity of 20 kcfs over daily average flow in May | **SOS 2c**<br>• Operate reservoirs within 1 foot above MOP from April 16 to July 31<br>• Same as SOS 1a for rest of year | **SOS 4c**<br>Same as SOS 2c |
| | **SOS 1b**<br>Same as 1a, except:<br>• No minimum flow limit (11,500 cfs) during fall and winter<br>• No fish-related rate of change in flows in May | **SOS 2d**<br>Same as SOS 2c | |

| | SOS 1 | SOS 2 | SOS 4 |
|---|---|---|---|
| **LOWER COLUMBIA** | **SOS 1a**<br>• Normal operations at 4 lower Columbia projects (generally within 3 to 5 feet of full pool, daily and weekly fluctuations)<br>• Restricted operation of Bonneville second powerhouse | **SOS 2c**<br>Same as SOS 1a except: lower John Day to minimum irrigation pool (approx. 262.5 feet) from April 15 to Aug. 31; operate within 1.5 feet of forebay range, unless need to raise to avoid irrigation impacts | **SOS 4c**<br>Same as SOS 2c, except operate John Day within 2 feet of elevation 263.5 feet Nov. 1 through June 30 |
| | **SOS 1b**<br>Same as 1a, except no restrictions on Bonneville second powerhouse | **SOS 2d**<br>Same as SOS 2c | |

KAF = 1.234 million cubic meters

MAF = 1.234 billion cubic meters

## Table 4–1. SOS Alternative–6

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b**<br>• Draft 2 feet per day starting Feb. 18<br>• Operate at natural river level, approx. 95 to 115 ft below full pool, April 16-Aug. 31; drawdown levels by project as follows, in feet:<br>Lower Granite 623<br>Little Goose 524<br>L. Monumental 432<br>Ice Harbor 343<br>• Operate within 3 to 5 ft of full pool rest of year<br>• Refill from natural flows and storage releases<br>**SOS 5c**<br>Same as SOS 5b, except drawdowns are permanent once natural river levels reached; no refill | **SOS 6b**<br>• Draft 2 feet per day starting April 1<br>• Operate 33 feet below full pool April 16-Aug. 31; drawdown levels by project as follows, in feet:<br>Lower Granite 705<br>Little Goose 605<br>L. Monumental 507<br>Ice Harbor 407<br>• Operate over 5-foot forebay range once drawdown elevation reached<br>• Refill from natural flows and storage releases<br>• Same as SOS 1a rest of year<br>**SOS 6d**<br>• Draft Lower Granite 2 feet per day starting April 1<br>• Operate Lower Granite near 705 ft for 4 1/2 months, April 16-Aug. 31 | **SOS 9a**<br>• Operate 33 feet below full pool (see SOS 6b) April 1-Aug. 31 to meet L. Granite flow targets (see Dworshak); same as SOS 1a rest of year<br>• Spill to achieve 80/80 FPE up to total dissolved gas cap of 120% daily average; spill cap 60 kcfs at all projects<br>**SOS 9b**<br>• Operate at MOP, with 1 foot flexibility April 1-Aug. 31; same as SOS 1a rest of year<br>• Spill to achieve 80/80 FPE up to total dissolved gas cap of 120% daily average; spill caps range from 18 kcfs at L. Monumental to 30 kcfs at L. Granite<br>**SOS 9c**<br>• Operate 35 to 45 feet below full pool April 1-June 15 to meet L. Granite flow targets (see Dworshak), refill by June 30; same as SOS 1a rest of year<br>• Spill to achieve 80/80 FPE, as in SOS 9b | **SOS PA**<br>• Operate at MOP with 1 foot flexibility between April 10 - Aug. 31<br>• Refill three lower Snake River pools after Aug. 31, Lower Granite after Nov. 15<br>• Spill to achieve 80% FPE up to total dissolved gas cap of 115% 12-hour average; spill caps range from 7.5 kcfs at L. Monumental to 25 kcfs at Ice Harbor |

| SOS 5 | SOS 6 | SOS 9 | SOS PA |
|---|---|---|---|
| **SOS 5b**<br>Same as SOS 2, except operate John Day within 1.5 feet above elevation 257 feet (MOP) from May 1 through Aug. 31; same as SOS 2c rest of year<br>**SOS 5c**<br>Same as SOS 5b | **SOS 6b**<br>Same as SOS 5<br>**SOS 6d**<br>Same as SOS 5 | **SOS 9a**<br>• Same as SOS 5, except operate John Day within 1 foot above elevation 257 feet April 15-Aug. 31<br>• McNary flow targets as described for Grand Coulee<br>• Spill to achieve 80/80 FPE, up to total dissolved gas cap of 120% daily average, as derived by agencies<br>**SOS 9b**<br>• Same as SOS 2, except operate John Day at minimum irrigation pool or 262.5 feet with 1 foot of flexibility from April 16-Aug. 31<br>• McNary flow targets as described for Grand Coulee<br>• Spill to achieve 80/80 FPE, up to total dissolved gas cap of 120% daily average, as derived by Corps<br>**SOS 9c**<br>Same as SOS 9b, except operate John Day at minimum operating pool | **SOS PA**<br>• Pool operations same as SOS 2c, except operate John Day at 257 feet (MOP) year-round, with 3 feet of flexibility March-Oct. and 5 feet of flexibility Nov.-Feb.<br>• Spill to achieve 80% FPE up to total dissolved gas cap of 115% 12-hour average; spill caps range from 9 kcfs at John Day to 90 kcfs at The Dalles |

1 kcfs = 28 cms

1 ft = 0.3048 meter

project operating requirements, HYDROSIM will simulate elevations, flows, spill, storage content and power generation for each project or river control point for the 50–year period. For more detailed information, please refer to Appendix A, River Operation Simulation.

The following section describes the final alternatives and reviews the rationale for their inclusion in the Final EIS.

### 4.1.1 SOS 1-Pre–ESA Operation

This alternative represents one end of the range of the SOR strategies in terms of their similarity to historical system operations. This strategy reflects Columbia River system operations before changes were made as a result of the ESA listing of three Snake River salmon stocks. This SOS has two options:

- **SOS 1a (Pre–Salmon Summit Operation)** represents operations as they existed from 1983 through the 1990–91 operating year, including Northwest Power Act provisions to restore and protect fish populations in the basin. Specific volumes for the Water Budget would be provided from Dworshak and Brownlee reservoirs to attempt to meet a target flow of 85 kcfs (2,380 cms) at Lower Granite Dam in May. Sufficient flows would be provided on the Columbia River to meet a target flow of 134 kcfs (3,752 cms) at Priest Rapids Dam in May. Lower Snake River projects would operate within 3 to 5 feet (0.9 to 1.5 m) of full pool. Other projects would operate as they did in 1990–91, with no additional water provided from the Snake River above Brownlee Dam.
- **SOS 1b (Optimum Load–Following Operation)** represents operations as they existed prior to changes resulting from the Northwest Power Act. It is designed to demonstrate how much power could be produced if most flow–related operations to benefit anadromous fish were eliminated including: the Water Budget; fish spill requirements; restrictions on operation of Bonneville's second powerhouse; and refill targets for Libby, Hungry Horse, Grand Coulee, Dworshak, and Albeni Falls. It assumes that transportation would be used to the maximum to aid juvenile fish migration.

### 4.1.2 SOS 2-Current Operations

This alternative reflects operation of the Columbia River system with interim flow improvement measures made in response to ESA listings of Snake River salmon. It is very similar to the way the system operated in 1992 and reflects the results of ESA Section 7 consultation with NMFS then. The strategy is consistent with the 1992–93 operations described in the Corps' *1993 Interim Columbia and Snake Rivers Flow Improvement Measures Supplemental EIS* (SEIS). SOS 2 also most closely represents the recommendations issued by the NMFS Snake River Salmon Recovery Team in May 1994. Compared to SOS 1, the primary changes are additional flow augmentation in the Columbia and Snake Rivers and modified pool levels at lower Snake and John Day reservoirs during juvenile salmon migration. This strategy has two options:

- **SOS 2c (Final SEIS Operation- No Action Alternative)** matches exactly the decision made as a result of the 1993 SEIS. Flow augmentation water of up to 3.0 MAF (3.7 billion m$^3$) on the Columbia River (in addition to the existing Water Budget) would be stored during the winter and released in the spring in low–runoff years. Dworshak would provide at least an additional 300 KAF (370 million m$^3$) in the spring and 470 KAF (580 million m$^3$) in the summer for flow augmentation. System flood control shifts from Dworshak and Brownlee to Grand Coulee would occur through April as needed. It also provides up to 427 KAF (527 million m$^3$) of additional water from the Snake River above Brownlee Dam.
- **SOS 2d (1994–98 Biological Opinion)** matches the hydro operations contained in the 1994–98 Biological Opinion issued by NMFS in mid–1994. This alternative provides water for the existing Water Budget as well as additional water, up to 4 MAF, for flow augmenta-

tion to benefit the anadromous fish migration. The additional water of up to 4 MAF would be stored in Grand Coulee, Libby and Arrow, and provided on a sliding scale tied to runoff forecasts. Flow targets are established at Lower Granite and McNary.

In cases such as the SOR, where the proposed action is a new management plan, the No Action Alternative means continuing with the present course of action until that action is changed (46 FR 13027). Among all of the strategies and options, SOS 2c best meets this definition for the No Action Alternative.

### 4.1.3 SOS 4-Stable Storage Project Operation

This alternative is intended to operate the storage reservoirs to benefit recreation, resident fish, wildlife, and anadromous fish while minimizing impacts of such operation to power and flood control. Reservoirs would be kept full longer, but still provide spring flows for fish and space for flood control. The goal is to minimize reservoir fluctuations while moving closer to natural flow conditions. For the Final EIS, this alternative has one option:

- **SOS 4c (Stable Storage Operation with Modified Grand Coulee Flood Control)** applies year–round Integrated Rule Curves (IRCs) developed by the State of Montana for Libby and Hungry Horse. Other reservoirs would be managed to specific elevations on a monthly basis; they would be kept full longer, while still providing spring flows for fish and space for flood control. The goal is to minimize reservoir fluctuations while moving closer to natural flow conditions. Grand Coulee would meet elevation targets year–round to provide acceptable water retention times; however, upper rule curves would apply at Grand Coulee if the January to July runoff forecast at the project is greater than 68 MAF (84 billion $m^3$).

### 4.1.4 SOS 5-Natural River Operation

This alternative is designed to aid juvenile salmon migration by drawing down reservoirs (to increase the velocity of water) at four lower Snake River projects. SOS 5 reflects operations after the installation of new outlets in the lower Snake River dams, permitting the lowering of reservoirs approximately 100 feet (30 m) to near original riverbed levels. This operation could not be implemented for a number of years, because it requires major structural modifications to the dams. Elevations would be: Lower Granite – 623 feet (190 m); Little Goose – 524 feet (160 m); Lower Monumental – 432 feet (132 m); and Ice Harbor – 343 feet (105 m). Drafting would be at the rate of 2 feet (0.6 m) per day beginning February 18. The reservoirs would refill again with natural inflows and storage releases from upriver projects, if needed. John Day would be lowered as much as 11 feet (3.3 m) to minimum pool, elevation 257 feet (78.3 m), from May through August. All other projects would operate essentially the same as in SOS 1a, except that up to 3 MAF (3.7 billion $m^3$) of water (in addition to the Water Budget) would be provided to augment flows on the Columbia River in May and June. System flood control would shift from Brownlee and Dworshak to the lower Snake River projects. Also, Dworshak would operate for local flood control. This alternative has two options:

- **SOS 5b (Four and One–half Month Natural River Operation)** provides for a lower Snake River drawdown lasting 4.5 months, beginning April 16 and ending August 31. Dworshak would be drafted to refill the lower Snake River projects if natural inflow were inadequate for timely refill.
- **SOS 5c (Permanent Natural River Operation)** provides for a year–round drawdown, and projects would not be refilled after each migration season.

### 4.1.5 SOS 6-Fixed Drawdown

This alternative is designed to aid juvenile anadromous fish by drawing down one or all four lower Snake River projects to fixed elevations approximately 30 to 35 feet (9 to 10 m) below minimum operating pool. As with SOS 5, fixed drawdowns depend on prior structural modifications and could not be instituted for a number of years. Draft would be at the rate of 2 feet (0.6 m) per day beginning April 1. John Day would be lowered to elevation 257 feet (78.3 m) from May through August. All other projects would operate essentially the same as under SOS 1a, except that up to 3 MAF (3.7 billion m$^3$) of water would be provided to augment flows on the Columbia River in May and June. System flood control would shift from Brownlee and Dworshak to the lower Snake projects. Also, Dworshak would operate for local flood control. This alternative has two options:

- **SOS 6b (Four and One–half Month Fixed Drawdown)** provides for a 4.5–month drawdown at all four lower Snake River projects beginning April 16 and ending August 31. Elevations would be: Lower Granite – 705 feet (215 m); Little Goose – 605 feet (184 m); Lower Monumental – 507 feet (155 m); and Ice Harbor – 407 feet (124 m).
- **SOS 6d (Four and One–half Month Lower Granite Fixed Drawdown)** provides for a 4.5–month drawdown to elevation 705 feet at Lower Granite beginning April 16 and ending August 31.

### 4.1.6 SOS 9-Settlement Discussion Alternatives

This SOS represents operations suggested by USFWS and NMFS (as SOR cooperating agencies), the State fisheries agencies, Native American tribes, and the Federal operating agencies during the settlement discussions in response to a court ruling in the *IDFG v. NMFS* lawsuit. The objective of SOS 9 is to provide increased velocities for anadromous fish by establishing flow targets during the migration period and by carrying out other actions that benefit ESA–listed species. The specific options were developed by a group of technical staff representing the parties in the lawsuit. The group was known as the Reasonable and Prudent Alternatives Workgroup. They developed three possible operations in addition to the 1994–98 Biological Opinion. This strategy has three options:

- **SOS 9a (Detailed Fishery Operating Plan [DFOP])** establishes flow targets at The Dalles based on the previous year's end–of–year storage content, similar to how PNCA selects operating rule curves. Grand Coulee and other storage projects are used to meet The Dalles flow targets. Specific volumes of releases are made from Dworshak, Brownlee, and upper Snake River to try to meet Lower Granite flow targets. Lower Snake River projects are drawn down to near spillway crest level for 4 1/2 months. Specific spill percentages are established at run–of–river projects to achieve no higher than 120 percent daily average total dissolved gas. Fish transportation is assumed to be eliminated.
- **SOS 9b (Adaptive Management)** establishes flow targets at McNary and Lower Granite based on runoff forecasts. Grand Coulee and other storage projects are used to meet the McNary flow targets. Specific volumes of releases are made from Dworshak, Brownlee, and the upper Snake River to try to meet Lower Granite flow targets. Lower Snake River projects are drawn down to minimum operating pool levels and John Day is at minimum irrigation pool level. Specific spill percentages are established at run–of–river projects to achieve no higher than 120 percent daily average for total dissolved gas.
- **SOS 9c (Balanced Impacts Operation)** draws down the four lower Snake River projects to near spillway crest levels for 2 1/2 months during the spring salmon migration period. Full drawdown level is achieved on April 1. Refill begins after June 15. This alternative also provides 1994–98 Biological Opinion flow augmentation (as in SOS 2d), IRC operation at Libby and Hungry Horse, a reduced flow target at Lower Granite due to drawdown, limits on winter drafting at Albeni Falls, and spill to achieve no higher than 120 percent daily average for total dissolved gas.

### 4.1.7 SOS PA-Preferred Alternative

This SOS represents the operation recommended by NMFS and USFWS in their respective Biological Opinions issued on March 1, 1995. SOS PA is intended to support recovery of ESA–listed species by storing water during the fall and winter to meet spring and summer flow targets, and to to meet spring and summer flow targets, and to protect other resources by managing detrimental effects through maximum summer draft limits, by providing public safety through flood protection, and by providing for reasonable power generation. This SOS would operate the system during the fall and winter to achieve a high confidence of refill to flood control elevations by April 15 of each year, and use this stored water for fish flow augmentation. It establishes spring flow targets at McNary and Lower Granite based on runoff forecasts, and a similar sliding scale flow target at Lower Granite and a fixed flow target at McNary for the summer. It establishes summer draft limits at Hungry Horse, Libby, Grand Coulee, and Dworshak. Libby is also operated to provide flows for Kootenai River white sturgeon. Lower Snake River projects are drawn down to minimum operating pool levels during the spring and summer. John Day is operated at minimum operating pool level year–round. Specific spill percentages are established at run–of–river projects to achieve 80–percent FPE, with no higher than 115–percent 12–hour daily average for total dissolved gas measured at the forebay of the next downstream project.

### 4.1.8 Rationale for Selection of the Final SOSs

Table 4–2 summarizes the changes to the set alternatives from the Draft EIS to the Final EIS. SOS 1a and 1b are unchanged from the Draft EIS. SOS 1a represents a base case condition and reflects system operation during the period from passage of the Northwest Power Planning and Conservation Act until ESA listings. It provides a baseline alternative that allows for comparison of the more recent alternatives and shows the recent historical operation. SOS 1b represents a limit for system operation directed at maximizing benefits from development–oriented uses, such as power generation, flood control, irrigation and navigation and away from natural resources protection. It serves as one end of the range of alternatives and provides a basis for comparison of the impacts to power generation from all other alternatives. Public comment did not recommend elimination of this alternative because it serves as a useful milepost. However, the SOR agencies recognize it is unlikely that decisions would be made to move operations toward this alternative.

In the Draft EIS, SOS 2 represented current operation. Three options were considered. Two of these options have been eliminated for the Final EIS and one new option has been added. SOS 2c continues as the No Action Alternative. Maintaining this option as the No Action Alternative allows for consistent comparisons in the Final EIS to those made in the Draft EIS. However, within the current practice category, new operations have been developed since the original identification of SOS 2c. In 1994, the SOR agencies, in consultation with the NMFS and USFWS, agreed to an operation, which was reflected in the 1994–98 Biological Opinion. This operation (SOS 2d) has been modeled for the Final EIS and represents the most "current" practice. SOS 2d also provides a good baseline comparison for the other, more unique alternatives. SOS 2a and 2b from the Draft EIS were eliminated because they are so similar to SOS 2c. SOS 2a is identical to SOS 2c except for the lack of an assumed additional 427 KAF of water from the upper Snake River Basin. This additional water did not cause significant changes to the effects between SOS 2a and 2c. There is no reason to continue to consider an alternative that has impacts essentially equal to another alternative. SOS 2b is also similar to SOS 2c, except it modified operation at Libby for Kootenai River white sturgeon. Such modifications are included in several other alternatives, namely SOS 2d, 9a, 9c, and the Preferred Alternative.

SOS 3a and 3b, included in the Draft EIS, have been dropped from consideration in the Final EIS. Both of these alternatives involved anadromous fish flow augmentation by establishing flow targets based on runoff forecast on the Columbia and Snake Rivers. SOS 3b included additional water from the upper Snake River Basin over what was assumed for SOS 3a. This operation is now incorporated in several new alternatives, including SOS 9a and 9b. Public comment also did not support continued consideration of the SOS 3 alternatives.

### Table 4–2. Summary of Alternatives in the Draft and Final EIS

| Draft EIS Alternatives | Final EIS Alternatives |
|---|---|
| SOS 1 Pre–ESA Operation | SOS 1 Pre–ESA Operation |
| SOS 1a Pre–Salmon Summit Operation | SOS 1a Pre–Salmon Summit Operation |
| SOS 1b Optimum Load Following Operation | SOS 1b Optimum Load Following Operation |
| SOS 2 Current Practice | SOS 2 Current Practice |
| SOS 2a Final Supplemental EIS Operation | SOS2c Final Supplemental EIS Operation – No–Action Alternative |
| SOS 2b Final Supplemental EIS with Sturgeon Operations at Libby | **SOS 2d 1994–98 Biological Opinion Operation** |
| SOS2c Final Supplemental EIS Operation – No–Action Alternative | |
| SOS 3 Flow Augmentation | |
| SOS 3a Monthly Flow Targets | |
| SOS 3b Monthly Flow Targets with additional Snake River Water | |
| SOS 4 Stable Storage Project Operation | SOS 4 Stable Storage Project Operation |
| SOS 4a1 Enhanced Storage Level Operation | **SOS 4c Enhanced Operation with modified Grand Coulee Flood Control** |
| SOS 4a3 Enhanced Storage Level Operation | |
| SOS 4b1 Compromise Storage Level Operation | |
| SOS 4b3 Compromise Storage Level Operation | |
| SOS 4c Enhanced Operation with modified Grand Coulee Flood Control | |
| SOS 5 Natural River Operation | SOS 5 Natural River Operation |
| SOS 5a Two Month Natural River Operation | SOS 5b Four and One Half Month Natural River Operation |
| SOS 5b Four and One Half Month Natural River Operation | **SOS 5c Permanent Natural River Operation** |
| SOS 6 Fixed Drawdown | SOS 6 Fixed Drawdown |
| SOS 6a Two Month Fixed Drawdown Operation | SOS 6b Four and One Half Month Fixed Drawdown Operation |
| SOS 6b Four and One Half Month Fixed Drawdown Operation | SOS 6d Four and One Half Month Lower Granite Drawdown Operation |
| SOS 6c Two Month Lower Granite Drawdown Operation | |
| SOS 6d Four and One Half Month Lower Granite Drawdown Operation | |
| SOS 7 Federal Resource Agency Operations | **SOS 9 Settlement Discussion Alternatives** |
| SOS 7a Coordination Act Report Operation | **SOS 9a Detailed Fishery Operating Plan** |
| SOS 7b Incidental Take Statement Flow Targets | **SOS 9b Adaptive Management** |
| SOS 7c NMFS Conservation Recommendations | **SOS 9c Balance Impacts Operation** |
| | **SOS Preferred Alternative** |

Bold indicates a new or revised SOS alternative

SOS 4 originally included 5 options in the Draft EIS. They were similar in operation and impact. In SOS 4a and 4b, the primary feature was the use of Biological Rule Curves for Libby and Hungry Horse reservoirs. SOS 4c also included these rule curves but went further by optimizing the operation of the other storage projects, particularly Grand Coulee and Dworshak. For the Final EIS, the SOR agencies have decided to update the alternative by substituting the IRC for the Biological Rule Curves and by eliminating SOS 4a and 4b. The IRCs are a more recent, acceptable version of minimum elevations for Libby and Hungry Horse. Significant public comment in support of this alternative with IRCs was received. Similar to SOS 2 above, SOS 4a and 4b were not different enough in operation or impacts to warrant continued consideration.

The Natural River (SOS 5) and the Spillway Crest Drawdown (SOS 6) alternatives in the Draft EIS originally included options for 2 months of drawdown to the appropriate pool level and 4 1/2 months of drawdown. The practicality of 2–month drawdowns was questioned during public review, particularly for the natural river. It did not appear that the time involved in drawing down the reservoirs and later refilling them provided the needed consideration for other uses. Flows are restricted to refill the reservoirs at a time when juvenile fall chinook are migrating downstream and various adult species are returning upstream. The 2 1/2 month drawdown strategies (SOS 5a, 6a, and 6c) have been dropped from the Final EIS. However, 2 1/2 month spillway crest drawdown at all four lower Snake projects is still an element in SOS 9c, so the impacts associated with this type of operation are assessed in the Final EIS.

A new option was added to SOS 5, namely SOS 5c. This option includes natural river drawdown of the lower Snake River projects on a permanent, year–round basis. The Corps received comment on this type of alternative during the review of Phase I of the SCS, a reconnaissance assessment of potential physical modifications for the system to enhance fish passage. Many believe the cost for such modification would be less than that required for periodic, temporary drawdowns, which would require specialized facilities to enable the projects to refill and operate at two different pool elevations.

SOS 7 Federal Resource Agencies Operations, which included 3 options in the Draft EIS, has been dropped from the Final EIS and replaced with an alternative now labeled as SOS 9 that also has 3 options. SOS 7a was suggested by the USFWS and represented the State fishery agencies and tribes' recommended operation. Since the issuance of the Draft EIS, this particular operation has been revised and replaced by the DFOP (SOS 9a). The SOR agencies received comment that the DFOP was not evaluated, but should be. Therefore, we have included this alternative exactly as proposed by these agencies; it is SOS 9a. SOS 7b and 7c were suggested by NMFS through the 1993 Biological Opinion. This opinion suggested two sets of flow targets as a way of increasing flow augmentation levels for anadromous fish. The flow targets came from the Incidental Take Statement and the Conservation Recommendation sections of that Biological Opinion. The opinion was judged as arbitrary and capricious as a result of legal action, and these operational alternatives have been replaced with other alternatives that were developed through settlement discussions among the parties to this lawsuit. SOS 7b and 7c have been dropped, but SOS 9b and 9c have been added to represent operations stemming from NMFS or other fishery agencies. In particular, SOS 9b is like DFOP but has reduced flow levels and forgoes drawdowns. It is a modification to DFOP. SOS 9c incorporates elements of operation supported by the State of Idaho in its "Idaho Plan." It includes a 2 1/2–month spillway crest drawdown on the lower Snake River projects and several other elements that attempt to strike a balance among the needs of anadromous fish, resident fish, wildlife and recreation.

Shortly after the alternatives for the Draft EIS were identified, the Nez Perce Tribe suggested an operation that involved drawdown of Lower Granite, significant additional amounts of upper Snake River water, and full pool operation at Dworshak (i.e., Dworshak remains full year round). It was labeled as SOS 8a. Hydroregulation of that operation was completed and provided to the Nez Perce Tribe. No technical response has been received from the Nez

Perce Tribe regarding the features or results of this alternative. However, the elements of this operation are generally incorporated in one or more of the other alternatives, or impose requirements on the system or specific projects that are outside the range considered reasonable. Therefore, this alternative has not been carried forward into the Final EIS.

The Preferred Alternative represents operating requirements contained in the 1995 Biological Opinions issued by NMFS and USFWS on operation of the FCRPS. These opinions resulted from ESA consultation conducted during late 1994 and early 1995, which were a direct consequence of the lawsuit and subsequent judgement in *Idaho v. NMFS*. The SOR agencies are now implementing this operating strategy and have concluded that it represents an appropriate balance among the multiple uses of the river. This strategy recognizes the importance of anadromous fish and the need to adjust river flows to benefit the migration of all salmon stocks, as well as the needs of resident fish and wildlife species at storage projects.

## 4.2 POTENTIAL WATER QUALITY IMPACTS

The direct effects of system operations on water quality are associated with the annual cycle of reservoir refilling and emptying and are generally immediate and of short duration. Based on available water quality information, there would be few long–term cumulative water quality impacts resulting directly from river system operations. These include the transport of sediment and contaminants and the build–up of nutrients.

### Total Dissolved Gas Saturation

Total dissolved gas concentration greater than saturation is caused primarily by spill –– water passing over the spillways of a dam. Spill can occur for several reasons. Water is sometimes intentionally released over spillways to help salmon and steelhead fingerings migrate to the sea. This usually happens during the spring and summer at projects where fish collection for transportation does not occur. Spill also occurs when there is more water in the river than the power system can use, either because of the lack of customers or because the generating and transmission systems are operating at maximum capacity. This forced spill may occur at any project.

There is a cumulative increase in the levels of total dissolved gas saturation as a result of spilling from the succession of dams in the system. This indicates that gas is not completely dissipated between projects where water from tributaries is not available. The correlation between saturation levels and the volume of spill is also strong and direct. Measurements conducted during the 1992 drawdown at Lower Granite and Little Goose Dams indicate variations associated with changes in reservoir and stilling basin elevations are of secondary importance.

Further development of information for gas supersaturation criteria may be needed for detailed balancing of total dissolved gas conditions and availability of water for outmigration. River flow augmentation, drawdowns, and spills have resulted in the need for short–term relief from the standards. Either the spillways will need to be modified so that total dissolved gas levels are at or below 110 percent, or the dissolved gas criterion should be changed based on scientifically valid in–situ biological monitoring. The large number of factors in fish mortality makes the assessment of harm from dissolved gas difficult to assess. It may not be possible to scientifically resolve disputes about the sub–lethal effects of dissolved gas. After structural improvements are installed it will be necessary to accept a standard, monitor, and stop spill when damage to fish is detected.

### Temperature

The major effect of the Columbia River dams on water temperature has been to delay the thermal maximums and cooling occurring in late summer, and perhaps a slight increase in overall average temperature. Lower reservoir pool elevation or increased outflow could affect water temperature downstream.

The release of cold Clearwater River water from the deep reservoir behind Dworshak Dam could reduce water temperature at Ice Harbor by about 1 degree F in some years. Temperature reductions at Lower Granite would be more significant, as would those in the North Fork and mainstem Clearwater.

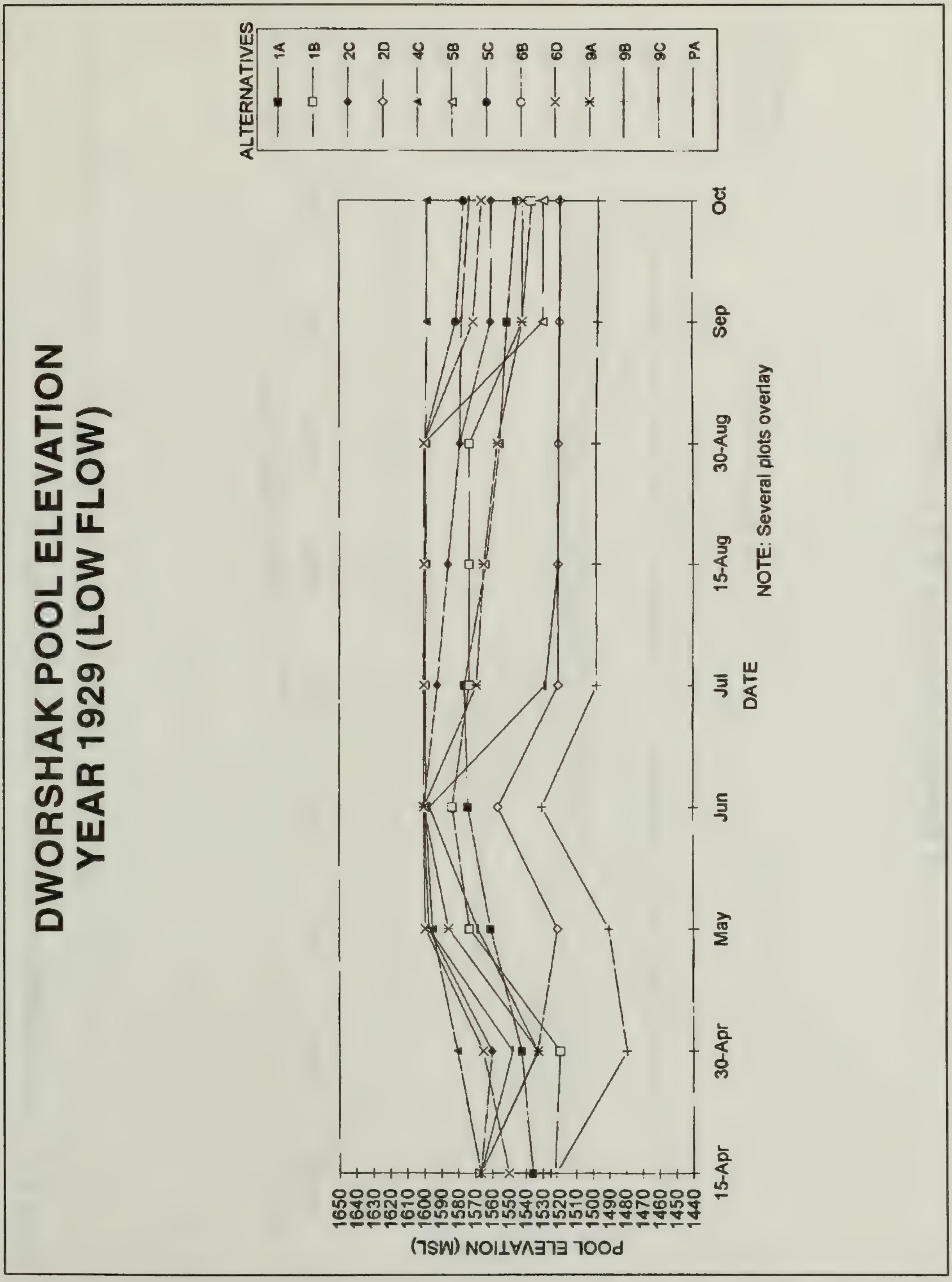
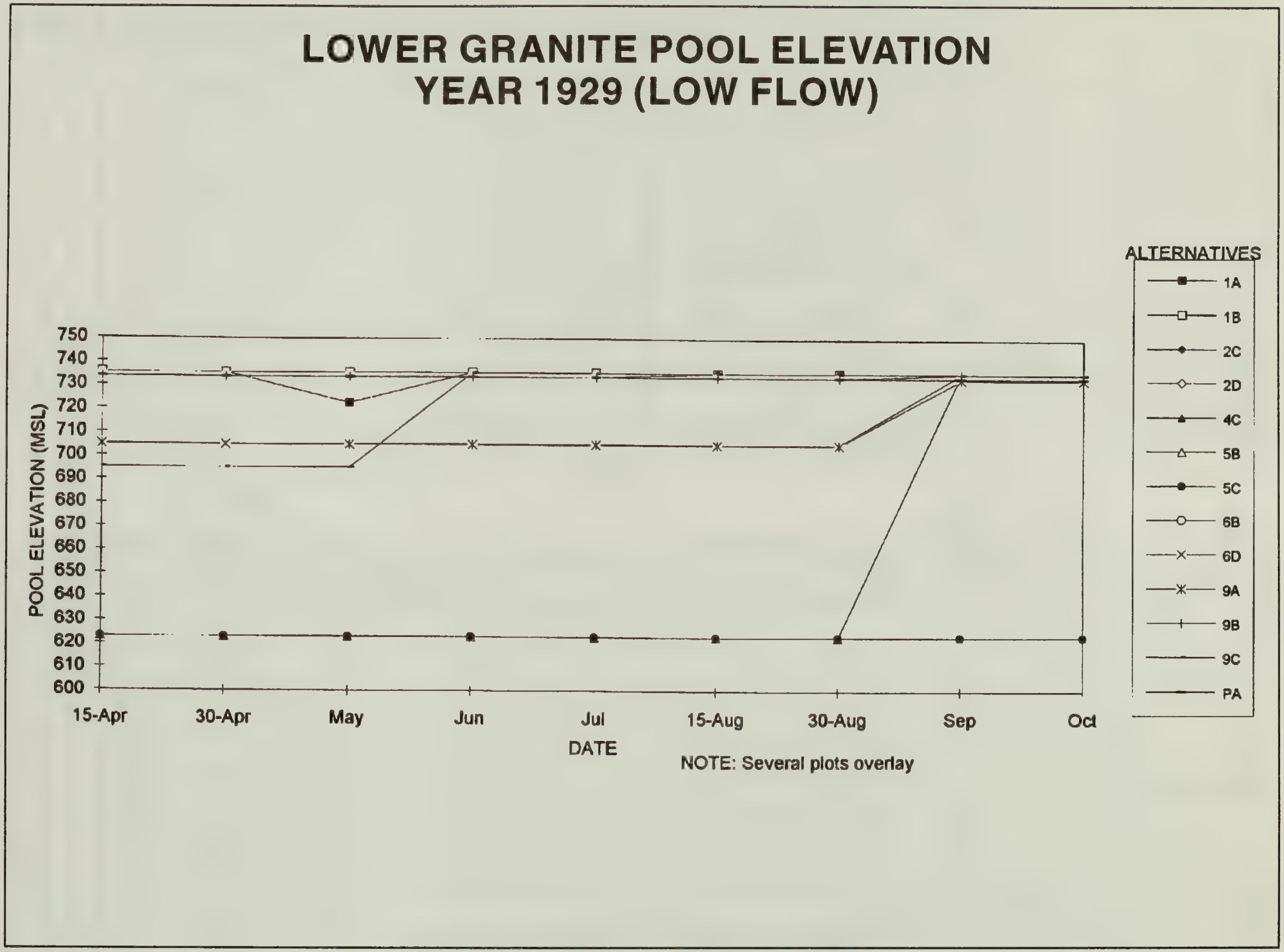


Figure 4–1. Dworshak Pool Elevation – 1929 (low flow year)



NOTE: Several plots overlay

Figure 4–2. Lower Granite Pool Elevation – 1929 (low flow year)

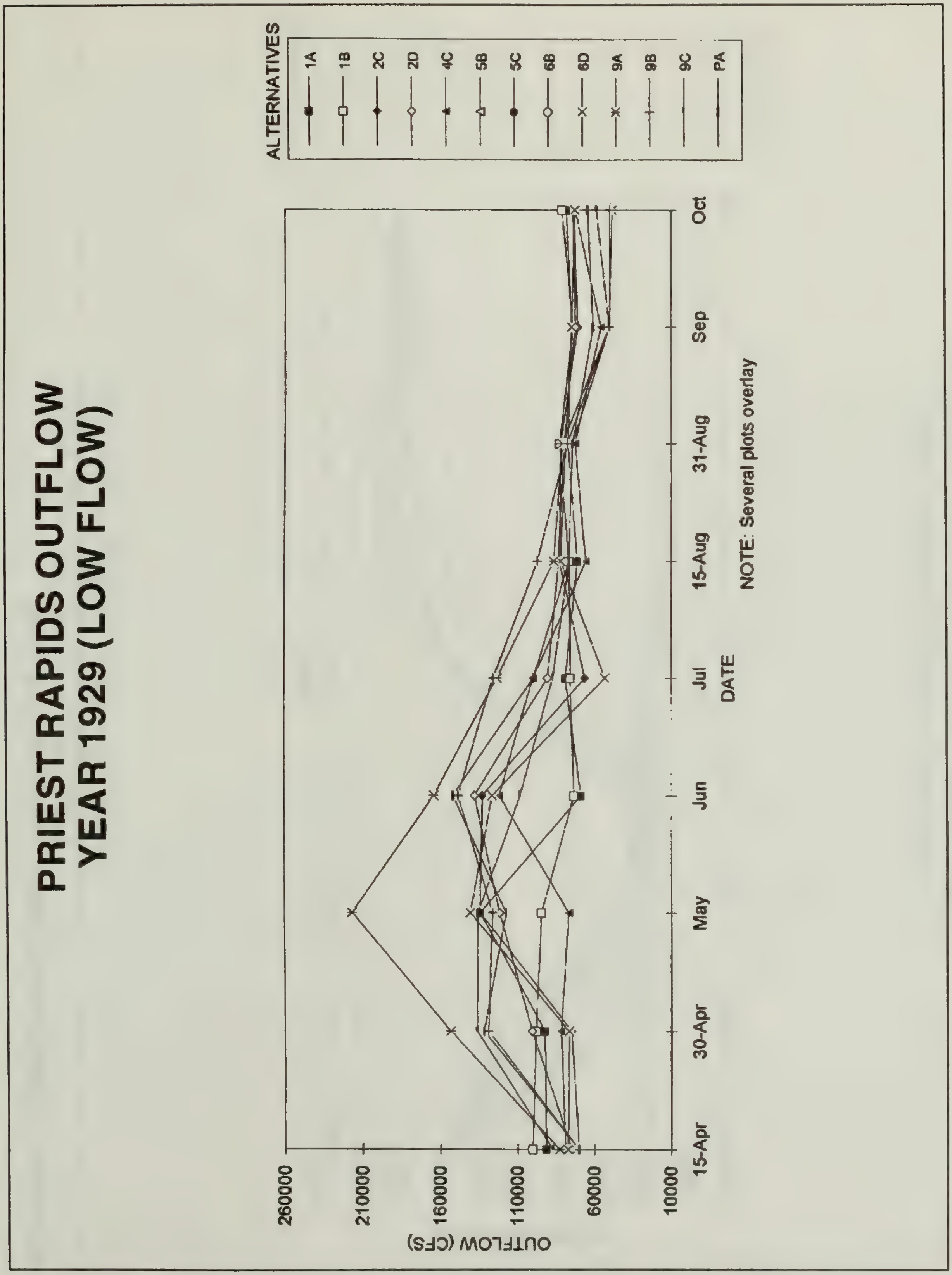


Figure 4–3. Priest Rapids Outflow – 1929 (low flow year)

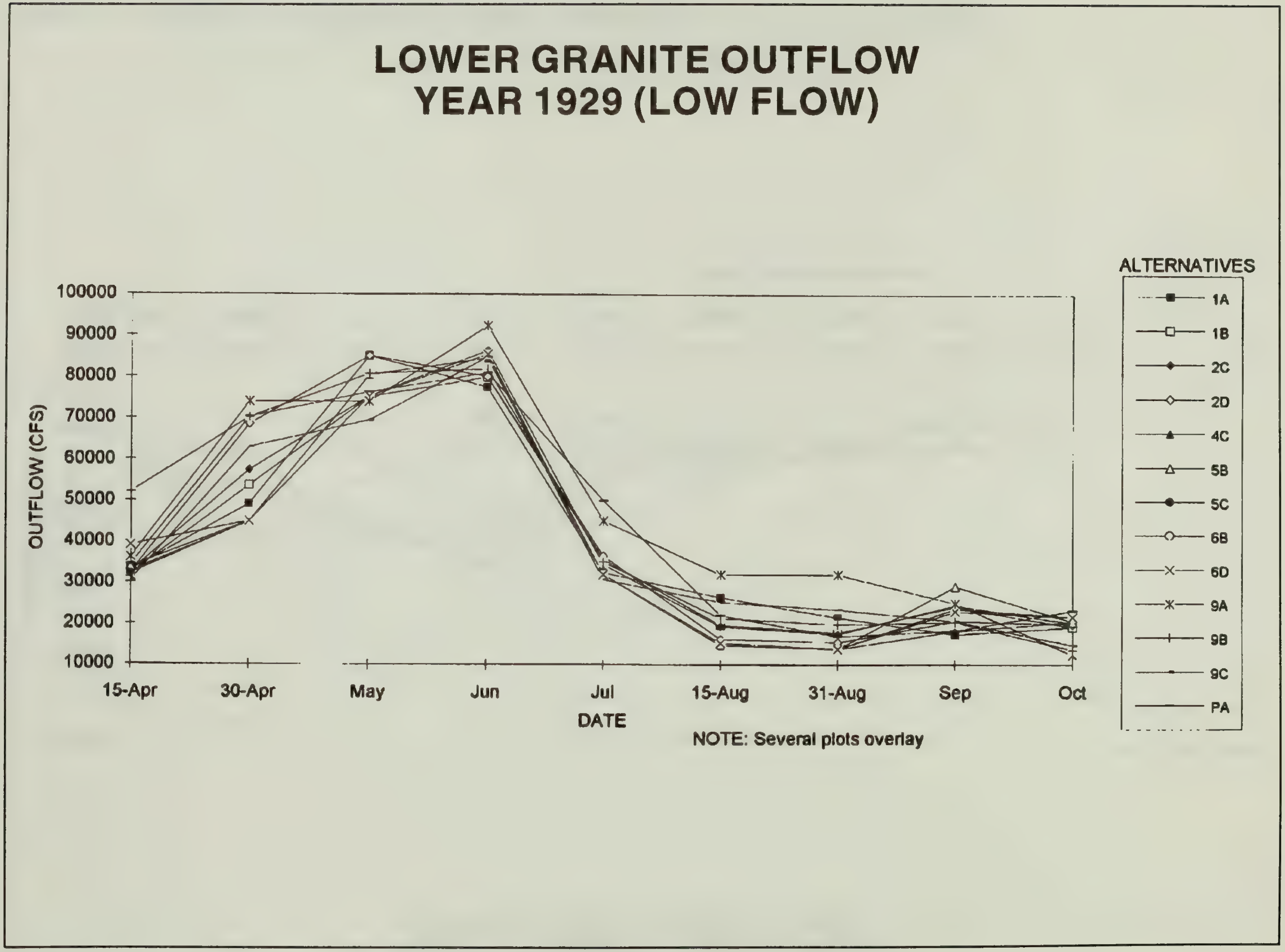


Figure 4–4. Lower Granite Outflow – 1929 (low flow year)

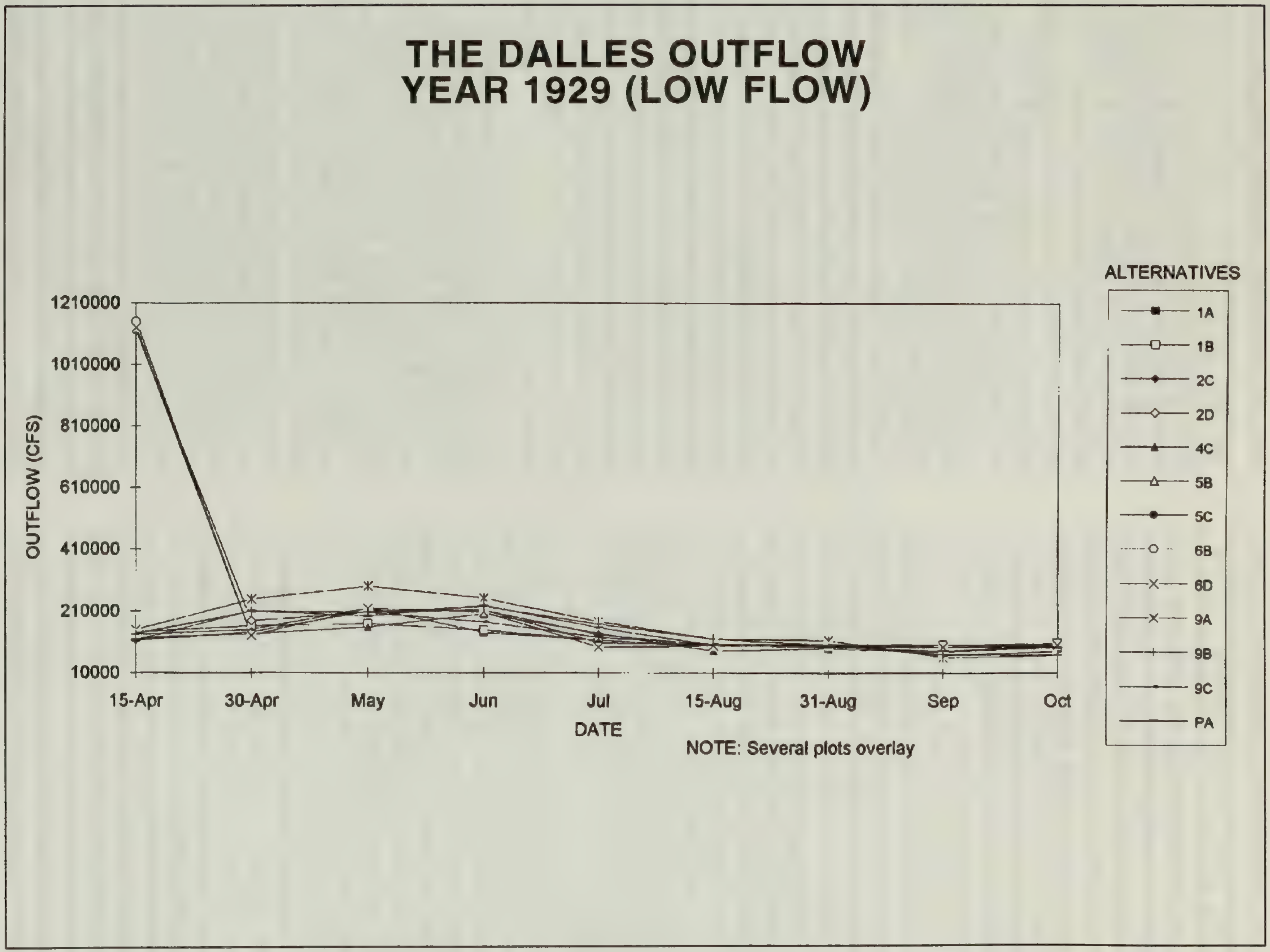


Figure 4–5. The Dalles Outflow – 1929 (low flow year)

Extreme drafting from Dworshak during late spring and summer, however, could change the thermal structure of the reservoir. Rapid lowering of the reservoir could increase the depth of warm water during summer stratification and potentially increase the temperature of discharge. If the discharge temperature is significantly increased, the use of Dworshak flow to cool the lower Snake River as a mitigation measure would not be as effective. Thermal effects would not be cumulative, as the reservoir re–establishes isothermal conditions, 39°F (4°C), during the fall/winter turnover.

Because of higher temperatures in the upper Snake River, releases from Brownlee might result in slightly higher temperature in the lower Snake. Water quality in the Lower Snake would be slightly improved by releases from Dworshak, however it would be degraded by releases from Brownlee. Where flow augmentation would potentially decrease water quality, pool drawdown combined with augmentation measures might result in some improvement overall. In most cases, increased water velocities and depths would definitely improve reservoir water quality insofar as dissolved oxygen and water temperature is concerned.

Potential impacts of cool water releases from Grand Coulee appear limited. This project is not equipped with ports permitting the withdrawal of cooler water from lower elevations in the reservoir. Furthermore, the whole reach between Grand Coulee and McNary Dams consists mostly of a series of relatively shallow run–of–the–river projects that warm up and cool off quickly with ambient temperature.

#### Resuspension of Reservoir Sediment and Stream Erosion

As reservoir levels decrease and tributary streams adjust to these lower levels, sediment deposits in side channels and embayments would be incised. The impact of raindrops, sheetwash and wind on exposed shorelines would also contribute to erosion. Minor streambank erosion may be occurring due to increased velocities which allow mobilization of more and/or larger sediment. High spring flow can increase lateral streambank erosion through entrainment and undercutting.

Minor effects can also be seen in tributaries. Downstream from Libby Dam, for example, tributaries to the Kootenai River have been depositing alluvial fans across the flood plains. This is due to storage of the Kootenai's spring flows behind the dam to provide flood control. Lateral erosion of the streambank across from the fans occurs as the Kootenai flows around these fans. High spring releases from Libby would slightly increase the erosion of these fans. Wave action on unprotected shorelines will also contribute significantly to bank erosion.

The potential for resuspension of toxic sediments in reservoirs such as Lake Roosevelt (Grand Coulee Dam reservoir) as a result of the system operating strategies evaluated in the EIS cannot be assessed with certainty for lack of data. The millions of tons of smelter and pulp mill waste that reside in the bed of Lake Roosevelt for example are likely to be displaced in some manner. Existence of arsenic, lead, cadmium, copper, lead, zinc, mercury, dioxins, furans, and PCBs has also been mentioned. According to the U.S. Geological Survey Open File Report 94–315, "cadmium, copper, lead, zinc, and mercury levels in sediments *exceed the severe–effect level on aquatic biota...*"

The relationship between sediment reentrainment (especially the reexposure to the aquatic environment) and reservoir operations is an area requiring further study. Before any significant changes to dam operations are proposed, the full impacts of those changes on both endangered species and human populations need to be fully evaluated. A good case in point is operation affecting McNary Reservoir which contains sediments discharged over the years by the Snake River and radioactive isotopes from the Hanford Reservation. Should pool drawdowns be performed at McNary, toxic contaminants entrained in the sediment column will very likely be disturbed.

System Operating Strategies which called for major fluctuations in the elevation of Lake Roosevelt have been dropped from consideration in the Final EIS. Nevertheless, the need for health studies is still present; the Corps of Engineers is currently working in this area with a contractor. Some testing has also already occurred during the drawdown at Lower Granite Dam in 1992 and other dredging operations. The results of the ecosystem restoration studies associated with the Elwa Dam removal proposal in Washington State will also be used in making impact assessment.

**Sedimentation**

Fluctuating water levels prevent wave action from creating shoreline equilibrium. At equilibrium, unconsolidated materials reach an angle of repose and little or no net erosion occurs. In its absence, fluctuating water levels annually increase shoreline erosion and slope instability; lake sedimentation is accelerated. Streambank erosion also increases with larger releases, which boost the velocity of water.

At present sedimentation is generally limited to sediment influx on the mainstem rivers. With the implementation of some System Operation Review alternatives, sediments already deposited in reservoirs would be redistributed. Coarser sediments would fall out in downstream portions of the reservoirs.

**Turbidity**

Increased flows and sediment loads will likely increase turbidity. Reservoir drafting could temporarily shift sediment depositional zones and increase downstream turbidity. In addition to flow rate, this condition can be affected by pool elevation. Riprap provides protection against wind and wave action but this is expensive mitigation.

Turbidity would be pronounced with alternatives calling for drawdown of 33 feet or more at Lower Snake River reservoirs. It would be generated by the rapid rate of pool drafting and refilling. More bank areas would be exposed to the effects of wind and precipitation effects. Exposed mud flats would be a source of sediments into the water and dust into the air. These effects, however, would decline after several years of operation; new depositional zones would be established.

Turbidity increase caused by maintenance dredging of Columbia River navigation channels is expected to be limited in time and space. None of the physical impacts associated with the System Operation Review alternatives is likely to lead to a significant change in the dredging or water quality conditions during the dredging.

**Contaminants and Other Water Quality Parameters**

Concerns about water quality contaminants are primarily associated with exposure to contaminated sediments, waste dumps, and sewer outfalls. As with turbidity, drawdown alternatives would produce the most serious effects. The 1992 drawdown test (Corps, 1992b) exposed some sewer lines in Lower Granite and some discharge water was observed to pond on exposed bed sediments.

There also is potential for contaminant leaching from encapsulated fills if there is seepage into the groundwater table. Lowering the pool below certain elevation would increase this potential.

There are a number of toxics of unknown source present below Bonneville Dam (Columbia River Estuary Study, TetraTech, 1991). Lowering the reservoirs will significantly increase sediment–associated toxics in the water column, as predicted suspended sediment concentrations increase by orders of magnitude with drawdown on the Lower Snake River to natural river level. A possible exception involves increased aeration and mixing as a result of higher flows, which could increase water column concentrations through resuspension of sediments. Lack of data precludes a judgment as to whether these processes constitute a significant or even measurable transport and fate mechanism.

Lowering the Snake reservoirs will expose small areas of additional sediment beds in localized regions of adjacent population centers and industrial activity. This might increase health risks if direct dermal contact is allowed to occur for prolonged periods. Data on contaminants in sediment are generally lacking so the significance of this potential exposure is unknown. Since contaminated sediments would most likely occur directly adjacent to industrial sites, however, prolonged physical contact would be minimized by limiting recreational access.

Exposure to contaminants will also be limited by the short–term nature of drawdown conditions. Sediment sampling prior to the 1992 drawdown test did not indicate significant human health or aquatic hazards. Decreases in outfall depths or outfall exposure resulting from the reservoir drawdowns could result in inadequate mixing of effluent with the receiving waters. Identification of the number, locations, and types of discharges which may be potentially affected is beyond the scope of this EIS.

Other relevant water quality parameters include dissolved oxygen, conductivity, and nutrients. Except for dissolved oxygen levels, which will increase proportionally to the increase in total dissolved gas, impacts to the other parameters should be relatively minor (and potentially decreased, if highly anaerobic sediments are entrained in the water). Flows released from Brownlee might have a minor adverse impact on the lower Snake River water quality because of the generally poorer existing quality conditions of the middle and upper Snake River water.

According to a July 1993 draft report by Laurie Weitkamp (Effects of Dams on the Columbia River Estuarine Environment), Columbia/Snake River reservoir operation altered sediment transportation rates and salinity intrusion, both of which affected the estuarine community. Because the intrusion of salt water into the estuary depends on the amount of fresh water resisting the salt water, decreased maximum flows and increased minimum flows regulated by dams have decreased the seasonal variability of saltwater intrusion. Dams also impact estuarine water quality, although high water volumes in the river strongly moderate these impacts. Without further studies of present–day physical processes and biotic interactions and without a large and accurate historic data base, the report indicated that true impacts of dams on the Columbia River estuary will be difficult to substantiate and quantify.

Last but not least, changes in system operation affecting timing, duration, and magnitude of project releases could potentially impact existing NPDES permits. These permits are issued based on dilution and any changes in water flow or circulation patterns could influence the dilution of these discharges. For the same reasons, existing federal permits issued under the Clean Water Act could also be affected by changes in system operation. Comparison of the various flow regimes with the minimum flow regulations recorded in the States' Water Rights books (e.g. Chapter 173–563 WAC for the main stem of the Columbia River in Washington State), although useful, was too refined a task for this System Operation Review. The monthly flow regulation studies performed in this Review are not detailed enough to determine whether the flow regime will cause water rights issued under the rule to be interrupted.

## 4.3 PREDICTED EFFECTS AND THEIR SIGNIFICANCE

### 4.3.1 Direct Effects on Water Temperature and Total Dissolved Gas

As indicated above, the results of water temperature and dissolved gas assessments are presented in terms of the number of days an established threshold was exceeded. For temperature, the threshold is 17.2 degrees C. For total dissolved gas, three thresholds were used, 110, 120, and 130 percent saturation. For sediment transport, assessment was only made for alternatives involving Lower Snake River reservoir drawdown. Results are summarized in Section 4.3.2.

Whenever applicable, actual water temperature and total dissolved saturation data were also provided for reference purposes. The analysis was based on five years for water temperature (1929, 1959, 1962, 1973, and 1974) and 6 years for dissolved gas (1938, 1959, 1962, 1973, 1974, and 1977). These years were selected to cover the typical range of low to high reservoir pool elevations and spilled discharges for the 50–year (1929–78) simulation period.

Included in the results for each location and each alternative are:

1) average values for all 5 or 6 years analyzed;
2) highest values reached in any of those years;
3) lowest values reached in any of those years;
4) values for individual years, and
5) totals for average values.

Results shown in this chapter cover all locations represented in the models, using the abbreviations listed in Table 4–3. Two abbreviation sets were used for maximum readability.

The amount of detail may appear excessive for general readers but is needed for field workers and reviewers. What happens in high flow years and, in some cases, low flow years is important information.

**SOS 1: Pre–ESA Operation**

- **SOS 1a (Pre–Salmon Summit Operation)**
- **SOS 1b (Optimum Load–Following Operation)**

### Table 4–3. Location Abbreviations

| Location | Water Temperature | Dissolved Gas |
|---|---|---|
| Dworshak | DW | |
| Brownlee | BN | |
| Oxbow | OX | |
| Hells Canyon | HC | |
| Lower Granite | GR | LWG |
| Little Goose | GS | LGS |
| Lower Monumental | LM | LMN |
| Ice Harbor | IH | IHR |
| Grand Coulee | GC | |
| Chief Joseph | CH | CHJ |
| Wells | WE | WEL |
| Rocky Reach | RR | RRH |
| Rock Island | RI | RIS |
| Wanapum | WA | WAN |
| Priest rapids | PR | PRD |
| McNary–Washington | MW | |
| McNary–Oregon | MO | |
| McNary | | MCN |
| John Day | JD | JDA |
| The Dalles | TD | TDA |
| Bonneville | BO | BON |

To provide a historical perspective of actual conditions that prevailed during the 1984–1991 period, actual observed water temperatures and dissolved gas saturation levels during the fish migration season (measured at 15 foot depths at the dam forebays) are given in Table 4–4. For example, the maximum instantaneous water temperature at Chief Joseph Dam varies from a high of 24.7 degrees C in 1986 to a low of 18.2 degrees C in 1986.

These values were collected by one instrument and may not be representative of the average condition of the river. Also, upper river instruments generally stopped operating after the end of the juvenile outmigration. Unusually high and low values and other suspicious values have been removed.

## Table 4–4. Range of Maximum Observed TDG and Water Temperature (WT) during 1984–1991 (Instantaneous Values)

| | TDG% | | | | WT(C) | | | |
|---|---|---|---|---|---|---|---|---|
| | High | | Low | | High | | Low | |
| Location | (%) | year | (%) | year | (C) | year | (C) | year |
| Int'l Boundary | 137 | 1991 | 123 | 1987 | 24.1 | 1986 | 16.9 | 1987 |
| Below Grand Coulee | 139 | 1986 | 111 | 1987 | 22.0 | 1991 | 17.9 | 1988 |
| Chief Joseph | 125 | 1991 | 113 | 1987 | 24.7 | 1985 | 18.2 | 1986 |
| Wells | 126 | 1986 | 112 | 1987 | 30.4 | 1985 | – | 1986 |
| Rocky Reach | 132 | 1990 | 111 | 1987 | 26.5 | 1985 | – | 1988 |
| Rock Island | 131 | 1990 | 112 | 1987 | 23.8 | 1990 | – | 1988 |
| Priest Rapids | 133 | 1990 | 122 | 1987 | 25.0 | 1985 | 19.6 | 1987 |
| Lower Granite(*) | 112 | 1986 | 111 | 1989 | 26.5 | 1990 | 21.7 | 1989 |
| Little Goose | 128 | 1984 | 110 | 1987 | – | 1991 | 18.5 | 1984 |
| Lower Monumental | 130 | 1986 | 111 | 1987 | 25.9 | 1990 | 18.5 | 1984 |
| Ice Harbor | 141 | 1986 | 115 | 1986 | – | 1990 | – | 1985 |
| McNary–WA | 128 | 1984 | 115 | 1987 | 25.2 | 1987 | – | 1985 |
| McNary–OR | 133 | 1984 | 119 | 1986 | 25.8 | 1991 | 16.2 | 1984 |
| John Day | 124 | 1986 | 112 | 1984 | 24.8 | 1991 | 17.9 | 1985 |
| The Dalles | 134 | 1986 | 110 | 1987 | 26.3 | 1991 | 19.3 | 1984 |
| Bonneville | 123 | 1986 | 107 | 1987 | 25.4 | 1989 | 20.3 | 1984 |
| Warrendale–OR | 134 | 1986 | 109 | 1987 | 25.0 | 1985 | 21.5 | 1989 |

Data provided below are numbers of days when predicted water temperature (or total dissolved gas saturation) exceed 17.2 degrees (or the indicated saturation levels). Data in the first row, labeled HIGH, are the highest number of days during the five (or six) years used in the analysis. Data in the second row, AVER, are the averages for the same years. Finally, data in the third row, LOW, are the lowest number of days for the years. Results related to water temperature are presented first, followed by those related to total dissolved gas.

| | DW | BN | OX | HC | GR | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 1a | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 83 | 92 | 92 | 94 | 62 | 66 | 71 | 73 | 78 | 80 | 82 | 97 | 97 | 94 | 94 | 101 |
| AVER | 0 | 63 | 66 | 68 | 74 | 81 | 85 | 81 | 35 | 42 | 54 | 60 | 64 | 69 | 71 | 82 | 90 | 88 | 89 | 91 |
| LOW | 0 | 54 | 57 | 57 | 65 | 74 | 80 | 55 | 0 | 6 | 25 | 47 | 51 | 53 | 54 | 64 | 84 | 74 | 76 | 79 |
| Alternative 1b | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 83 | 82 | 88 | 88 | 62 | 65 | 69 | 73 | 78 | 80 | 82 | 97 | 93 | 95 | 96 | 100 |
| AVER | 0 | 63 | 66 | 68 | 69 | 78 | 83 | 86 | 35 | 42 | 53 | 59 | 63 | 67 | 70 | 81 | 90 | 89 | 89 | 91 |
| LOW | 0 | 54 | 57 | 57 | 62 | 72 | 80 | 83 | 0 | 6 | 27 | 48 | 50 | 52 | 53 | 64 | 84 | 74 | 77 | 80 |

Dissolved Gas Saturation

| Station: | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Alternative 1a | | | | | | | | | | | | | | |
| THRESHOLD=130 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 11 | 9 | 0 | 0 | 0 | 17 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 3 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 8 | 15 | 13 | 16 | 19 | 17 | 10 | 19 | 22 | 21 | 12 | 12 | 3 | 34 |
| AVERAGE | 1 | 3 | 2 | 3 | 3 | 3 | 2 | 5 | 9 | 7 | 2 | 2 | 1 | 6 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=110 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 53 | 48 | 45 | 68 | 70 | 86 | 27 | 30 | 89 | 83 | 76 | 98 | 97 | 95 |
| AVERAGE | 26 | 21 | 16 | 25 | 25 | 32 | 12 | 22 | 75 | 77 | 27 | 53 | 51 | 35 |
| LOW | 20 | 13 | 9 | 15 | 14 | 19 | 7 | 16 | 66 | 68 | 5 | 39 | 34 | 16 |
| Alternative 1b | | | | | | | | | | | | | | |
| THRESHOLD=130 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 11 | 9 | 0 | 0 | 0 | 17 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 3 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 6 | 14 | 12 | 16 | 19 | 16 | 10 | 19 | 22 | 21 | 11 | 11 | 5 | 32 |
| AVERAGE | 1 | 2 | 2 | 3 | 3 | 3 | 2 | 5 | 10 | 8 | 2 | 2 | 1 | 5 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=110 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 53 | 48 | 45 | 68 | 70 | 85 | 27 | 27 | 89 | 83 | 77 | 100 | 100 | 95 |
| AVERAGE | 27 | 21 | 17 | 26 | 26 | 33 | 12 | 21 | 72 | 75 | 27 | 53 | 50 | 34 |
| LOW | 20 | 14 | 9 | 15 | 14 | 20 | 7 | 15 | 55 | 64 | 2 | 0 | 0 | 10 |

**SOS 2. Current Operations**

- **SOS 2a (Final SEIS Operation Without Additional Snake Water)**
- **SOS 2b (Final SEIS Operation with New Operations at Libby for Sturgeon)**
- **SOS 2c (Final SEIS Operation ––No–Action Alternative)**

The "No Action Alternative" (Alternative 2C) calls for continuing the 1993 operations for the System Operation Review projects, with appropriate operational adjustments in case of favorable run–off conditions. Under this scenario, water quality conditions in the Columbia River Basin are not expected to change very much in the foreseeable future. This assumes that other point and nonpoint source pollutants remain at their present levels. There are essentially no cumulative impacts from year to year as a result of system operation. And except for total dissolved gas and sediment, reservoir system regulation is not the dominant factor affecting mainstem water quality.

Current operations resulted in frequent violation of the total dissolved gas standard (110 percent) because of both forced and unforced spill. Figure 4–6 is a plot of daily total dissolved gas saturation readings at Warrendale, six miles downstream from Bonneville Dam. Because violations of the total dissolved gas standard occur even under normal operations, an informal effort to relax that standard has been initiated. This would resolve the legal issue but effects on fish would remain. Structural alterations –– new "flip–lip" added to the remaining dams that do not already provide sufficient degasification –– are expected to reduce total dissolved gas to some extent. New and more efficient fish bypass systems would be helpful in view of the current standard of 80 percent fish passage efficiency tentatively set by the fishery agencies and tribes. Meeting this high a standard requires heavy spill at most, if not all, projects.

Dissolved oxygen, which has not been a problem in the past, is expected to continue to be maintained at satisfactory levels. No increases in sediment transport and therefore turbidity are predicted.

Even though the "No Action Alternative" does not affect water quality in the Columbia River Basin to any appreciable extent, the continuation of current operations is not an assured possibility because of emerging needs that transcend traditional water resource project benefits derived from power generation, flood control, and navigation.

With specific reference to the value measures adopted for the full–scale analysis, actual maximum values for water temperature and dissolved gas saturation recorded in 1992 are summarized in Table 4–5. Other analysis results follow in the same format as that used earlier in this chapter for SOS 1.

**Table 4–5. Maximum Observed TDG and Water Temperature (WT) in 1992 (Instantaneous Values)**

| Location | TDG percent | WT(C) |
|---|---|---|
| Int'l Boundary | 138 | 22.8 |
| Below Grand Coulee | 116 | 21.4 |
| Chief Joseph | 116 | 19.9 |
| Wells | 118 | 19.7 |
| Rocky Reach | 114 | 19.4 |
| Rock Island | 115 | 18.8 |
| Priest Rapids | – | – |
| Lower Granite(*) | 113 | 25.8 |
| Little Goose | 117 | 25.4 |
| Lower Monumental | 113 | 24.5 |
| Ice Harbor | 115 | 25.3 |
| McNary–WA | 122 | 25.8 |
| McNary–OR | 123 | 25.9 |
| John Day | 118 | 25.9 |
| The Dalles | 114 | 23.6 |
| Bonneville | 133 | 22.8 |
| Warrendale–OR | 131 | 22.8 |

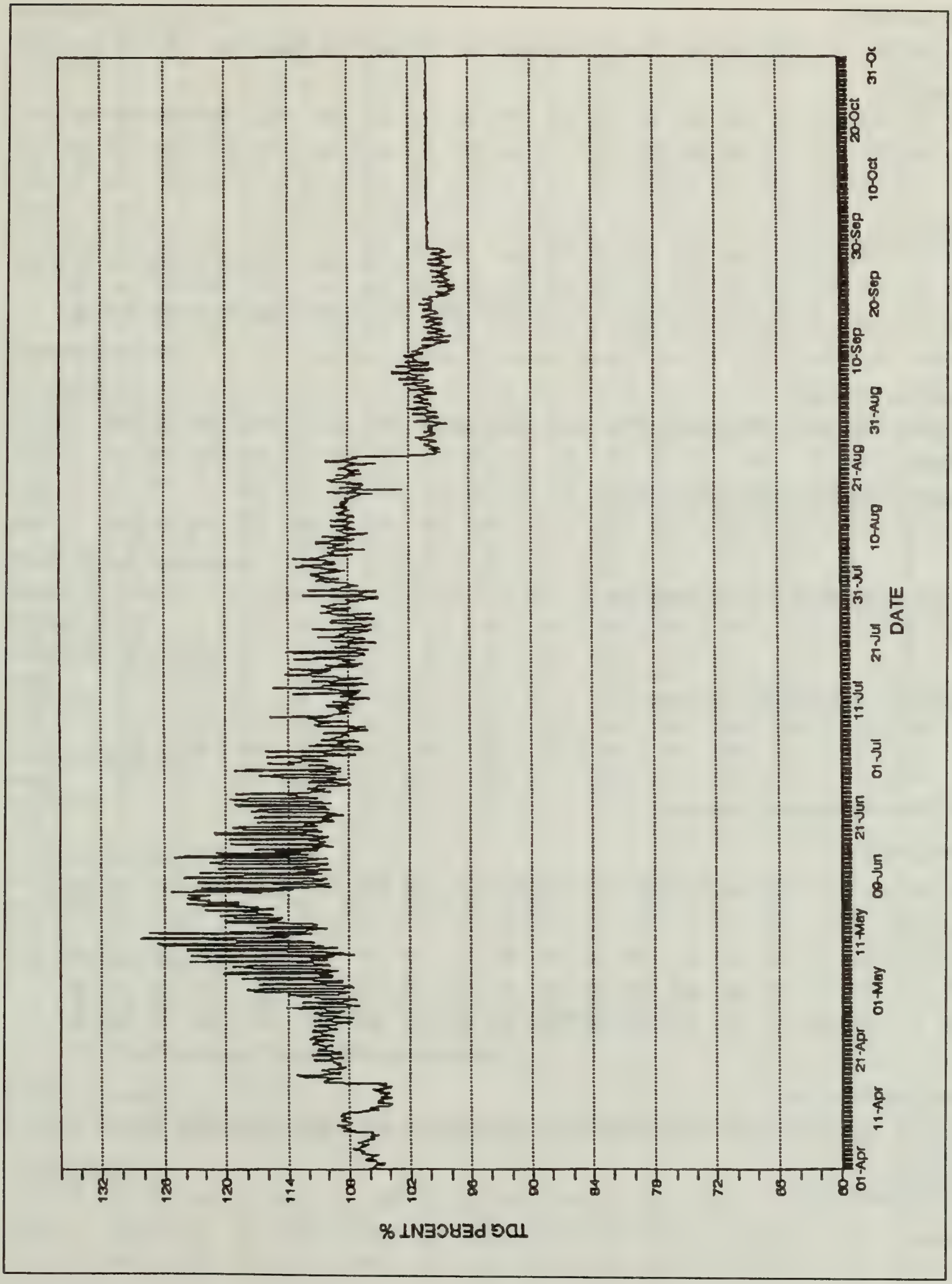


**Figure 4–6.** Daily Observed Total Dissolved Gas Saturation at Warrendale, Oregon

Water temperature

| Sta: | DW | BN | OX | HC | GR | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 2b | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 84 | 88 | 90 | 92 | 62 | 66 | 71 | 79 | 79 | 80 | 81 | 90 | 94 | 95 | 94 | 92 |
| AVER | 0 | 64 | 66 | 67 | 78 | 82 | 85 | 87 | 36 | 43 | 54 | 60 | 62 | 68 | 69 | 78 | 89 | 88 | 88 | 88 |
| LOW | 0 | 57 | 60 | 58 | 62 | 69 | 75 | 83 | 0 | 5 | 28 | 49 | 50 | 53 | 55 | 64 | 84 | 75 | 77 | 79 |
| Alternative 2c | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 80 | 85 | 83 | 88 | 90 | 92 | 62 | 63 | 66 | 79 | 79 | 80 | 80 | 88 | 93 | 93 | 94 | 92 |
| AVER | 0 | 65 | 67 | 69 | 78 | 82 | 85 | 87 | 35 | 41 | 53 | 61 | 64 | 69 | 70 | 78 | 89 | 87 | 88 | 88 |
| LOW | 0 | 58 | 61 | 59 | 62 | 69 | 75 | 82 | 0 | 6 | 29 | 48 | 51 | 53 | 54 | 64 | 84 | 74 | 75 | 78 |

Dissolved Gas Saturation

| Station: | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 2c | | | | | | | | | | | | | | |
| THRESHOLD=130 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 11 | 10 | 0 | 0 | 0 | 27 |
| AVER | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 5 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 5 | 12 | 7 | 16 | 20 | 15 | 10 | 19 | 22 | 20 | 12 | 11 | 3 | 101 |
| AVER | 1 | 2 | 1 | 3 | 3 | 3 | 2 | 5 | 6 | 5 | 2 | 2 | 1 | 23 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=110 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 57 | 58 | 52 | 88 | 91 | 97 | 27 | 27 | 74 | 61 | 70 | 95 | 101 | 127 |
| AVER | 27 | 22 | 18 | 36 | 30 | 43 | 13 | 21 | 50 | 45 | 21 | 48 | 48 | 91 |
| LOW | 20 | 13 | 10 | 19 | 14 | 28 | 7 | 16 | 34 | 37 | 0 | 33 | 1 | 8 |

**SOS 2d. (1994–98 Biological Opinion)**

Water temperature

| Sta: | DW | BN | OX | HC | GR | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 2d | | | | | | | | | | | | | | | | | | | | |
| HIGH | 26 | 81 | 84 | 87 | 87 | 90 | 92 | 94 | 62 | 69 | 73 | 74 | 75 | 81 | 83 | 92 | 94 | 94 | 96 | 96 |
| AVER | 9 | 60 | 63 | 70 | 79 | 85 | 88 | 92 | 47 | 52 | 59 | 63 | 65 | 72 | 74 | 83 | 92 | 90 | 91 | 91 |
| LOW | 0 | 51 | 52 | 62 | 67 | 77 | 82 | 89 | 32 | 40 | 44 | 51 | 53 | 64 | 65 | 73 | 88 | 82 | 82 | 84 |

Dissolved Gas Saturation

| Stat. | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 2d | | | | | | | | | | | | | | |
| THRESHOLD=130 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 8 | 9 | 6 | 2 | 0 | 0 | 21 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 4 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| THRESHOLD=120 PCT | | | | | | | | | | | | | | |
| HIGH | 5 | 21 | 12 | 27 | 38 | 34 | 9 | 17 | 19 | 18 | 14 | 13 | 7 | 87 |
| AVERAGE | 1 | 4 | 2 | 5 | 8 | 7 | 2 | 4 | 5 | 4 | 2 | 2 | 1 | 20 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=110 PCT | | | | | | | | | | | | | | |
| HIGH | 56 | 57 | 55 | 59 | 69 | 79 | 22 | 23 | 25 | 26 | 61 | 71 | 78 | 117 |
| AVERAGE | 24 | 22 | 19 | 20 | 23 | 33 | 9 | 17 | 21 | 21 | 17 | 36 | 33 | 78 |
| LOW | 13 | 10 | 7 | 6 | 5 | 14 | 5 | 11 | 14 | 17 | 0 | 17 | 13 | 46 |
| AVER | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### SOS 4. Stable Storage Project Operation

- **SOS 4c (Stable Storage Operation with Modified Grand Coulee Flood Control)**

Water temperature

Alternative 4c

| Sta: | DW | BN | OX | HC | GR | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HIGH | 0 | 80 | 83 | 87 | 90 | 91 | 93 | 94 | 63 | 69 | 75 | 75 | 75 | 78 | 80 | 92 | 96 | 97 | 98 | 98 |
| AVER | 0 | 65 | 67 | 71 | 83 | 87 | 88 | 91 | 48 | 52 | 59 | 64 | 66 | 72 | 74 | 83 | 92 | 91 | 92 | 92 |
| LOW | 0 | 58 | 59 | 63 | 76 | 81 | 83 | 88 | 34 | 39 | 44 | 50 | 54 | 66 | 67 | 75 | 88 | 83 | 84 | 84 |

Dissolved Gas Saturation

| Station: | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 4c | | | | | | | | | | | | | | |
| THRESHOLD=130 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 9 | 7 | 0 | 0 | 0 | 19 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 3 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PCT | | | | | | | | | | | | | | |
| HIGH | 3 | 9 | 5 | 16 | 29 | 25 | 8 | 16 | 18 | 18 | 10 | 11 | 5 | 88 |
| AVERAGE | 1 | 2 | 1 | 3 | 5 | 4 | 2 | 4 | 5 | 5 | 2 | 2 | 1 | 24 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=110 PCT | | | | | | | | | | | | | | |
| HIGH | 59 | 62 | 59 | 66 | 75 | 92 | 23 | 24 | 26 | 26 | 56 | 72 | 79 | 123 |
| AVERAGE | 24 | 21 | 18 | 19 | 22 | 31 | 10 | 18 | 23 | 22 | 14 | 42 | 33 | 75 |
| LOW | 13 | 10 | 7 | 7 | 6 | 11 | 5 | 13 | 19 | 19 | 0 | 26 | 17 | 27 |

### SOS 5. Natural River Operation

- **SOS 5b (Four and One–half Month Natural River Operation)**
- **SOS 5c (Permanent Natural River Operation)**

Water temperature

| Sta.: | DW | BN | OX | HC | GR | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 5b | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 71 | 85 | 85 | 84 | 62 | 63 | 65 | 79 | 81 | 87 | 93 | 97 | 95 | 95 | 95 | 93 |
| AVER | 0 | 64 | 66 | 67 | 61 | 66 | 70 | 80 | 33 | 38 | 46 | 57 | 60 | 69 | 72 | 83 | 87 | 87 | 88 | 88 |
| LOW | 0 | 57 | 60 | 58 | 57 | 60 | 64 | 74 | 0 | 0 | 19 | 39 | 42 | 48 | 51 | 63 | 83 | 75 | 76 | 78 |

Alternative 5c

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HIGH | 0 | 80 | 83 | 87 | 80 | 83 | 86 | 87 | 63 | 64 | 71 | 78 | 81 | 87 | 90 | 99 | 90 | 96 | 96 | 98 |
| AVE | 0 | 66 | 67 | 71 | 74 | 75 | 77 | 78 | 42 | 46 | 55 | 63 | 65 | 74 | 77 | 89 | 84 | 91 | 92 | 94 |
| LOW | 0 | 58 | 59 | 63 | 68 | 69 | 70 | 70 | 21 | 31 | 44 | 48 | 49 | 58 | 59 | 75 | 76 | 84 | 85 | 85 |

Dissolved Gas Saturation

| Sta.: | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 5b | | | | | | | | | | | | | | |
| THRESHOLD=130 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 3 | 10 | 5 | 16 | 20 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |
| AVERAGE | 1 | 2 | 1 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=110 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 57 | 58 | 50 | 89 | 90 | 94 | 6 | 6 | 3 | 2 | 48 | 79 | 83 | 127 |
| AVERAGE | 26 | 22 | 17 | 36 | 30 | 42 | 6 | 6 | 3 | 2 | 8 | 26 | 32 | 86 |
| LOW | 20 | 13 | 8 | 19 | 15 | 27 | 6 | 6 | 2 | 1 | 0 | 8 | 18 | 55 |
| Alternative 5c | | | | | | | | | | | | | | |
| THRESHOLD=130 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 4 | 2 | 7 | 19 | 15 | 50 | 50 | 0 | 0 | 0 | 0 | 0 | 22 |
| AVERAGE | 0 | 1 | 0 | 1 | 3 | 3 | 17 | 33 | 0 | 0 | 0 | 0 | 0 | 4 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=110 PCT | | | | | | | | | | | | | | |
| HIGH | 61 | 61 | 57 | 72 | 82 | 87 | 5 | 83 | 79 | 26 | 56 | 48 | 38 | 36 |
| AVERAGE | 21 | 19 | 16 | 18 | 18 | 19 | 5 | 83 | 78 | 5 | 9 | 8 | 6 | 6 |
| LOW | 13 | 10 | 7 | 6 | 3 | 2 | 5 | 83 | 79 | 0 | 0 | 0 | 0 | 0 |

### SOS 6. Fixed Drawdown

- **SOS 6b (Four and One–half Month Fixed Drawdown)**
- **SOS 6d (Four and One–half–Month Lower Granite Fixed Drawdown)**

Water temperature

| Sta.: | DW | BN | OX | HC | GR | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 6b | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 84 | 85 | 95 | 96 | 61 | 62 | 74 | 80 | 80 | 80 | 81 | 88 | 100 | 93 | 94 | 93 |
| AVER | 0 | 64 | 66 | 67 | 69 | 78 | 84 | 88 | 35 | 41 | 54 | 61 | 65 | 69 | 70 | 79 | 90 | 88 | 89 | 89 |
| LOW | 0 | 57 | 60 | 58 | 61 | 70 | 76 | 84 | 0 | 4 | 25 | 48 | 51 | 54 | 54 | 65 | 84 | 73 | 75 | 79 |

Alternative 6d

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HIGH | 0 | 77 | 79 | 84 | 84 | 83 | 93 | 93 | 61 | 62 | 74 | 80 | 80 | 80 | 81 | 88 | 96 | 93 | 94 | 93 |
| AVER | 0 | 64 | 66 | 67 | 68 | 77 | 82 | 87 | 35 | 41 | 54 | 61 | 65 | 69 | 70 | 79 | 89 | 87 | 88 | 88 |
| LOW | 0 | 57 | 60 | 58 | 60 | 70 | 75 | 82 | 0 | 4 | 25 | 48 | 51 | 54 | 54 | 65 | 84 | 73 | 76 | 78 |

Dissolved Gas Saturation

| Station: | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 6b | | | | | | | | | | | | | | |
| THRESHOLD=130 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 3 | 0 | 0 | 0 | 30 |
| AVER | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 5 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 3 | 10 | 5 | 16 | 20 | 14 | 6 | 18 | 21 | 19 | 8 | 7 | 0 | 101 |
| AVER | 1 | 2 | 1 | 3 | 3 | 2 | 1 | 5 | 6 | 5 | 1 | 1 | 0 | 22 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=110 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 57 | 58 | 50 | 89 | 90 | 94 | 34 | 29 | 50 | 50 | 68 | 93 | 97 | 127 |
| AVER | 26 | 22 | 17 | 36 | 31 | 42 | 14 | 19 | 27 | 27 | 18 | 41 | 42 | 89 |
| LOW | 20 | 13 | 8 | 19 | 15 | 27 | 7 | 15 | 14 | 20 | 0 | 26 | 27 | 9 |
| Alternative 6d | | | | | | | | | | | | | | |
| THRESHOLD=130 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 9 | 7 | 0 | 0 | 0 | 31 |
| AVER | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 5 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 3 | 10 | 5 | 16 | 20 | 14 | 6 | 18 | 21 | 20 | 12 | 8 | 3 | 101 |
| AVER | 1 | 2 | 1 | 3 | 3 | 2 | 1 | 4 | 5 | 5 | 2 | 1 | 1 | 23 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=110 PERCENT SATURATION | | | | | | | | | | | | | | |
| HIGH | 57 | 58 | 50 | 89 | 90 | 94 | 34 | 29 | 70 | 65 | 71 | 97 | 102 | 127 |
| AVER | 26 | 22 | 17 | 35 | 31 | 42 | 14 | 22 | 46 | 42 | 21 | 47 | 30 | 90 |
| LOW | 20 | 13 | 8 | 19 | 15 | 27 | 7 | 15 | 32 | 29 | 0 | 33 | 27 | 58 |

**SOS 9. Settlement Discussion alternatives**

- **SOS 9a (Detailed Fishery Operating Plan)**
- **SOS 9b (Adaptive Management)**
- **SOS 9c (Idaho Balanced Impacts Operation)**

Water Temperature

| Stat.: | DWBN | | OX | HC | GR | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 9a | | | | | | | | | | | | | | | | | | | | |
| HIGH | 70 | 89 | 90 | 92 | 89 | 90 | 89 | 92 | 59 | 66 | 73 | 75 | 76 | 79 | 80 | 92 | 93 | 94 | 94 | 96 |
| AVER | 11 | 78 | 79 | 80 | 83 | 85 | 87 | 89 | 49 | 54 | 59 | 65 | 68 | 73 | 74 | 84 | 92 | 91 | 92 | 92 |
| LOW | 0 | 73 | 75 | 74 | 75 | 81 | 83 | 86 | 38 | 42 | 45 | 54 | 59 | 64 | 68 | 74 | 89 | 86 | 86 | 86 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 9b | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 86 | 87 | 91 | 88 | 90 | 92 | 94 | 63 | 66 | 73 | 75 | 75 | 81 | 82 | 92 | 94 | 93 | 94 | 96 |
| AVER | 0 | 67 | 70 | 75 | 84 | 87 | 88 | 91 | 50 | 54 | 59 | 64 | 67 | 73 | 74 | 84 | 92 | 91 | 91 | 92 |
| LOW | 0 | 60 | 62 | 68 | 81 | 83 | 85 | 88 | 35 | 41 | 44 | 51 | 57 | 67 | 67 | 74 | 90 | 84 | 85 | 86 |
| Alternative 9c | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 86 | 87 | 91 | 89 | 88 | 89 | 91 | 63 | 69 | 74 | 75 | 75 | 82 | 88 | 93 | 94 | 97 | 97 | 98 |
| AVE | 0 | 67 | 70 | 75 | 82 | 85 | 86 | 89 | 48 | 53 | 59 | 64 | 67 | 74 | 76 | 85 | 92 | 92 | 92 | 93 |
| LOW | 0 | 60 | 62 | 68 | 75 | 80 | 81 | 86 | 33 | 40 | 45 | 52 | 56 | 66 | 66 | 74 | 91 | 83 | 84 | 84 |

Dissolved Gas Saturation

| Station: | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 9a | | | | | | | | | | | | | | |
| THRESHOLD=130 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 13 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 2 | 0 | 8 | 19 | 14 | 5 | 16 | 40 | 17 | 6 | 65 | 3 | 62 |
| AVERAGE | 0 | 0 | 0 | 1 | 3 | 2 | 1 | 9 | 29 | 14 | 1 | 45 | 1 | 58 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 5 | 0 | 21 | 0 | 53 |
| THRESHOLD=110 PCT | | | | | | | | | | | | | | |
| HIGH | 59 | 61 | 56 | 69 | 80 | 90 | 73 | 58 | 93 | 85 | 71 | 125 | 132 | 134 |
| AVERAGE | 29 | 27 | 23 | 26 | 28 | 38 | 54 | 45 | 70 | 65 | 26 | 122 | 130 | 131 |
| LOW | 18 | 14 | 12 | 11 | 11 | 22 | 21 | 24 | 37 | 36 | 4 | 119 | 127 | 128 |
| Alternative 9b | | | | | | | | | | | | | | |
| THRESHOLD=130 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 10 | 7 | 0 | 0 | 0 | 14 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 3 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 6 | 2 | 9 | 22 | 17 | 28 | 22 | 47 | 22 | 11 | 25 | 7 | 56 |
| AVERAGE | 0 | 1 | 0 | 2 | 4 | 3 | 15 | 13 | 40 | 15 | 2 | 9 | 1 | 43 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 5 | 29 | 6 | 0 | 0 | 0 | 22 |
| THRESHOLD=110 PCT | | | | | | | | | | | | | | |
| HIGH | 68 | 76 | 71 | 86 | 92 | 97 | 131 | 111 | 108 | 109 | 73 | 123 | 138 | 135 |
| AVERAGE | 30 | 28 | 25 | 29 | 30 | 36 | 115 | 97 | 98 | 93 | 31 | 114 | 129 | 129 |
| LOW | 18 | 13 | 8 | 7 | 5 | 12 | 94 | 86 | 78 | 74 | 2 | 107 | 122 | 119 |
| Alternative 9c | | | | | | | | | | | | | | |
| THRESHOLD=130 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 10 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PCT | | | | | | | | | | | | | | |
| HIGH | 6 | 13 | 11 | 16 | 26 | 22 | 6 | 17 | 34 | 15 | 1 | 45 | 1 | 51 |
| AVERAGE | 1 | 2 | 2 | 3 | 5 | 4 | 3 | 3 | 19 | 3 | 0 | 11 | 0 | 40 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 5 | 0 | 0 | 0 | 0 | 26 |

THRESHOLD=110 PCT

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HIGH | 49 | 53 | 49 | 58 | 68 | 82 | 56 | 55 | 69 | 74 | 53 | 115 | 134 | 135 |
| AVERAGE | 22 | 20 | 17 | 19 | 20 | 28 | 51 | 52 | 58 | 60 | 13 | 95 | 117 | 126 |
| LOW | 13 | 10 | 7 | 6 | 6 | 12 | 43 | 47 | 45 | 46 | 0 | 69 | 102 | 115 |

Water Temperature

Alternative PA

| Sta.: | DW | BN | OX | HC | GR | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HIGH | 39 | 86 | 87 | 91 | 90 | 92 | 94 | 95 | 62 | 65 | 70 | 74 | 74 | 78 | 81 | 92 | 94 | 95 | 94 | 96 |
| AVER | 23 | 71 | 73 | 75 | 76 | 83 | 86 | 92 | 48 | 52 | 58 | 62 | 64 | 70 | 73 | 84 | 92 | 91 | 91 | 92 |
| LOW | 0 | 65 | 67 | 68 | 66 | 75 | 79 | 84 | 34 | 39 | 44 | 47 | 49 | 55 | 58 | 73 | 85 | 83 | 83 | 83 |

Dissolved Gas Saturation

Alternative PA

| Station: | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| THRESHOLD=130 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 90 | 70 | 0 | 0 | 0 | 10 |
| AVERAGE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| THRESHOLD=120 PCT | | | | | | | | | | | | | | |
| HIGH | 0 | 4 | 3 | 8 | 23 | 17 | 9 | 18 | 20 | 19 | 12 | 12 | 12 | 22 |
| AVERAGE | 0 | 1 | 1 | 1 | 4 | 3 | 2 | 4 | 5 | 4 | 2 | 2 | 3 | 12 |
| LOW | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| THRESHOLD=110 PCT | | | | | | | | | | | | | | |
| HIGH | 69 | 74 | 70 | 85 | 93 | 97 | 25 | 27 | 28 | 27 | 58 | 61 | 138 | 135 |
| AVERAGE | 28 | 25 | 21 | 24 | 26 | 34 | 12 | 20 | 23 | 23 | 13 | 32 | 125 | 122 |
| LOW | 18 | 13 | 8 | 7 | 7 | 13 | 6 | 13 | 15 | 18 | 0 | 4 | 116 | 112 |

### 4.3.2 Effects on Sediments

Drawdown scenarios covered Lower Granite Reservoir drawn down to 1) minimum operating pool, 2) 33 feet, 3) 52 feet, and 4) 0 feet, natural streambed. Drawdown simulated lasted two and four and one half months in each case. High, average, and low flow years were simulated separately in a five year sequence. Details of sediment transport results are provided in Technical Exhibit G. Figures 4–7, 4–8, and 4–9 are graphs showing the predicted volume of sediment eroded at the end of the first and fifth years of operation in each case under average flow conditions.

Using river mile 120 as reference point, the total volume of sediments transported (in tons) estimated by HEC–6 model would be as follows in the first and fifth years:

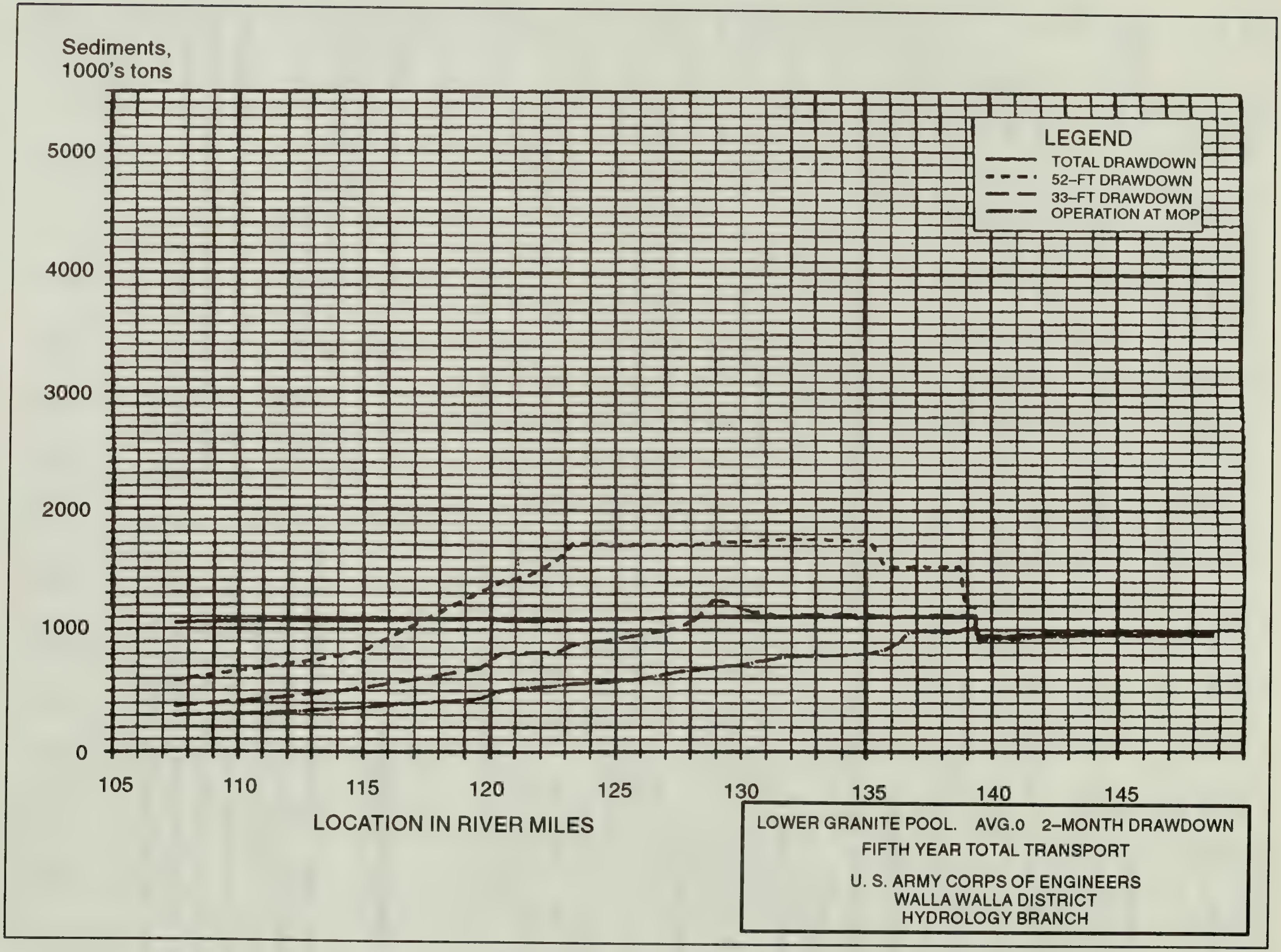


**Figure 4–7.** **Predicted Sediment Transport at Lower Granite Pool, 2–Month Drawdown, End of 5th Year**

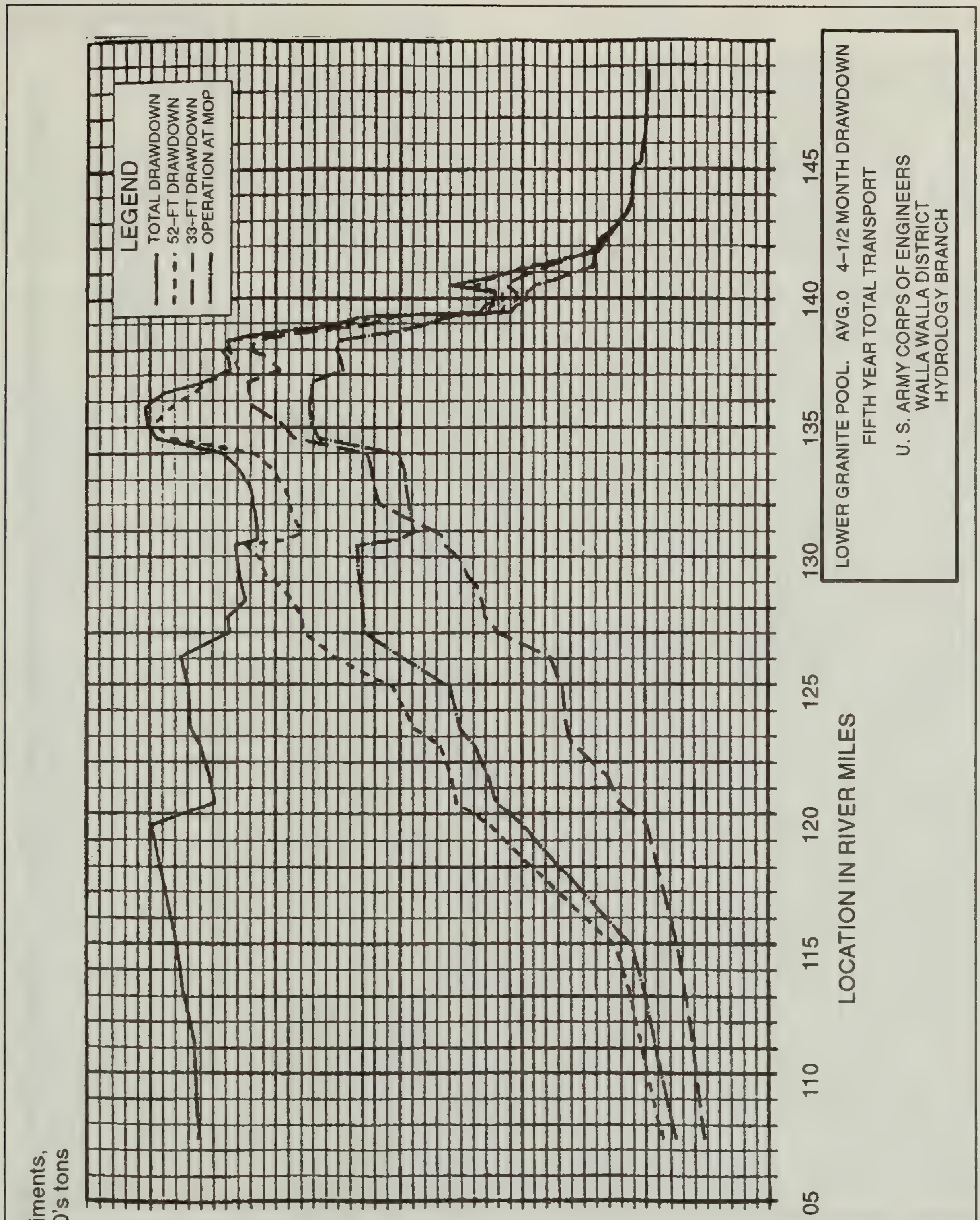


**Figure 4–8. Predicted Sediment Transport, Lower Granite Pool, 4–1/2 Month Drawdown, End of 1st Year**

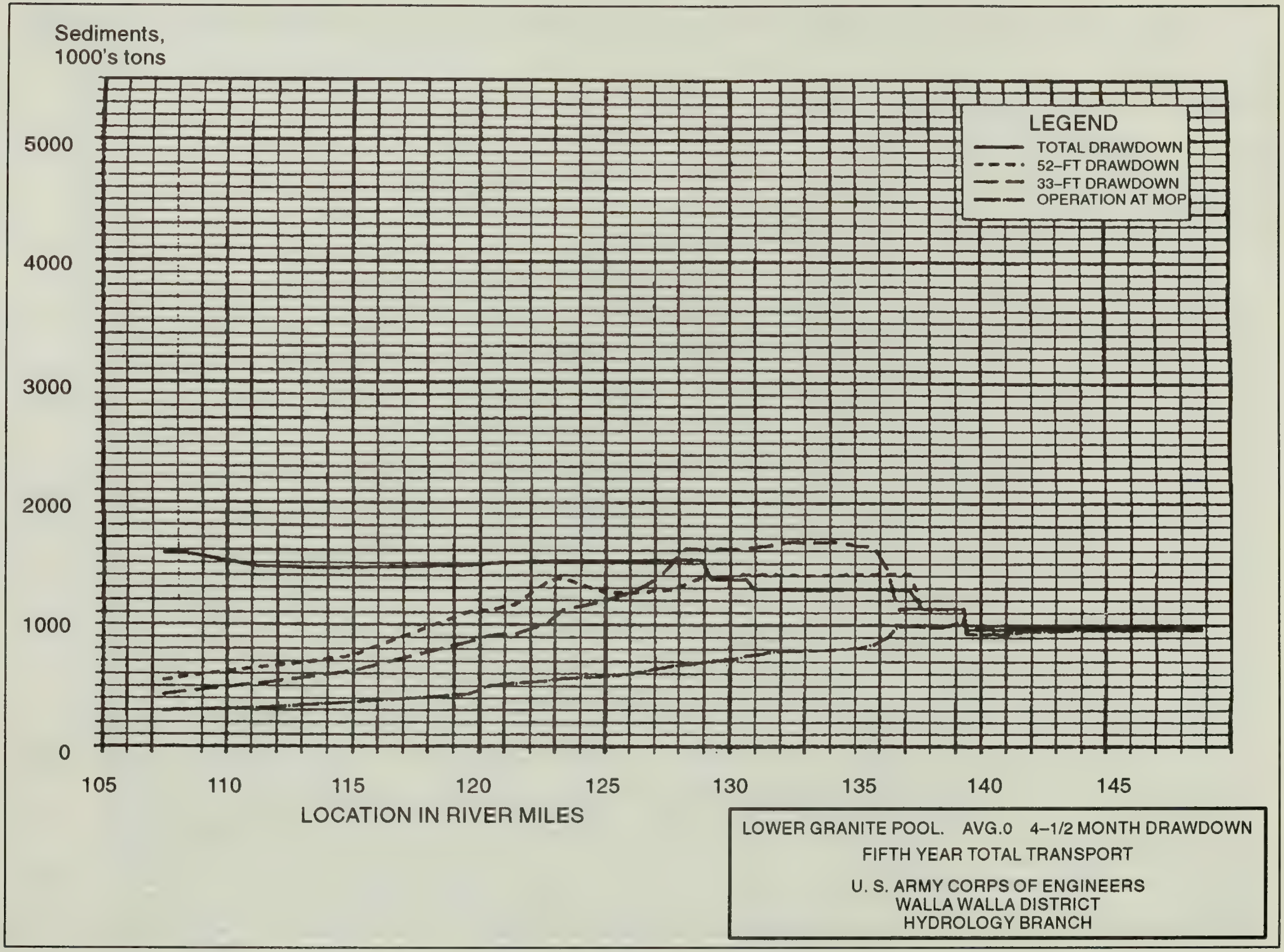


**Figure 4–9. Predicted Sediment Transport, Lower Granite Pool, 4–1/2 Month Drawdown, End of 5th Year**

### Table 4–6. Predicted Sediment Load at RM 120

| | First Year | Fifth Year |
|---|---|---|
| Two–month drawdown: | | |
| Minimum Pool | 500,000 | 500,000 |
| 33 ft (6c) | 900,000 | 700,000 |
| 52 ft (*) | 2,100,000 | 1,100,000 |
| Natural streambed (5a) | 4,400,000 | 1,400,000 |
| 4–1/2 month drawdown: | | |
| Minimum Pool | 1,000,000 | 500,000 |
| 33 ft (6d) | 2,100,000 | 900,000 |
| 52 ft (*) | 2,400,000 | 1,100,000 |
| Natural streambed (5b) | 4,700,000 | 1,500,000 |

**Note: (*) Not an SOR alternative; shown for reference purposes only**

Sediment loadings predicted by HEC–6 were used as input to HEC–5Q model. Results of the HEC–5Q model are provided in Table 4–7 for DDT, total lead, and silt at Lower Granite, Ice Harbor, Priest Rapids, and John Day Dams in terms of exceedence of selected treshold values. Figures 4–10 and 4–11 graphically depict DDT exceedence percentage at Lower Granite and Ice Harbor Dams. The results indicate that only DDT and lead exceedences vary between the base case and drawdown SOSs.

The newer or revised system operating strategies (SOS) introduced later in the System Operation Review were analyzed using extrapolations from earlier studies documented in the draft Environmental Impact Statement. Criteria used included flow and drawdown specifications and current velocities during drawdown. New and/or revised alternatives included 2d, 4c, 5c, 9a, 9b, 9c and PA. The only new alternative that is not comparable to any of those documented in the draft Environmental Impact Statement is SOS 5c due to its full year drawdown. Using to the technique described in Technical Exhibit K, the following conclusions were derived:

(1) SOS 9b and PA are similar to SOS 2a;

(2) the sediment transport impacts of SOS 9b and 2c are the same;

(3) potential exists for SOS 9a having greater sediment concentrations than 6b;

(4) SOS 9a is expected cause more reservoir bottom sediments to be scoured;

(5) SOS 6b sediment concentrations are representative of SOS 9b; and

(6) there is no solid basis for a reliable estimate of sediment transport for 5c.

### 4.3.3 Indirect Effects

The most important indirect impacts on water quality are those associated with fish and aquatic life, recreation, domestic and industrial water supply, and irrigation. They are indicated in the values established for water temperature, dissolved gas saturation, and sediment concentrations. The more days thresholds for these parameters are exceeded, the more serious indirect effects are expected to be.

In general, fish can adjust to optimum upper and lower levels of water temperatures under natural environmental changes. They can, however, be deeply depressed by shifts away from these optimum ranges (Fisheries Handbook of Engineering Requirements and Biological Criteria, Corps of Engineers, 1991). Adults may die without spawning if subjected to high water temperatures for long periods. Mortalities can occur to eggs if temperatures are above or below the tolerance range. Growth of juvenile fish, their resistance to diseases, and swimming speeds, are all related to temperature.

Dissolved gases, particularly nitrogen, are also harmful to fish. Nitrogen is absorbed into the blood stream, causing gas bubbles which can be fatal to fish. It is generally believed that exposure to high levels of dissolved gas (120 percent or higher) for extended periods can be lethal to both juvenile and adult fish.

Excessive sediment loadings generally elevate turbidity levels. Relatively large quantities (500 to 1,000 ppm) of suspended water–borne material can be carried for short periods of time without detriment to fish. But some species of fish, bass and bluegill, are unable to spawn in excessively turbid water. The harmfulness of siltation on salmonid spawning and the incubation of eggs depend upon the amount and type of material and when it is deposited.

The loss of water clarity reduces the enjoyment of recreationists, particularly anglers. Heavy bank erosion and the resulting high volume of sediment transported can increase the need for dredging to maintain navigation channels. It can also increase the cost of treating domestic water supplies. On the other hand, dams and the greater frequency of low flows may benefit some species in the Columbia River estuary. Plankton entering the estuary from upstream reservoirs dissolves on contact with salt water and adds to the estuarine food web for fish and other aquatic microorganisms (Weitkamp, 1993).

Implementation of some of the System Operation Review alternatives could produce many of these indirect effects, which are evaluated in detail by work groups addressing the resources involved. One of the studies not undertaken by the water quality work group is the impacts of groundwater discharges to the Columbia and Snake Rivers. Groundwater discharges may be altered if drastic pool drawdown options are pursued. These changes may be in the form of increased levels of naturally occurring constituents, or they may also be seen from man-made contaminants as a result of land use activities that take place within the Columbia Drainage. Shallower aquifer depletion will increase, and this may decrease time of travel from river–bank locations to discharge points into the river.

Also, the water quality work group has not looked into potential pollution concentrations and their impacts on the overall water quality conditions with respect to both people and fish. However, the work group did recommend monitoring as a means for assessing this potential problem. It is possible that the mixing area for discharges into the river could change. Also, health problems would most likely result from people eating fish, not from contact. Contact pollution may occur if people were exposed at outfalls before the discharge is diluted.

### 4.3.4 Efficiency of Alternatives

The most efficient alternatives from the standpoint of water quality would maintain water temperature at or below optimal levels for all organisms (including fish), create little or no spill (keeping total dissolved gas saturation levels low), and minimize erosion, sediment transport, and turbidity.

None of the System Operation Review alternatives meets all these criteria. Some of the reasons are given below:

- water temperature control potential is limited in the Columbia River Basin,
- few reservoirs are deep enough to provide storage for cold water, and
- Grand Coulee and Brownlee have no low elevation ports for releasing cool water.

  Of the two reservoirs equipped with selective withdrawal facilities, Libby is too far from the fish migration routes and Dworshak release volume is too small in relation to Snake River flows to produce dramatic reductions in temperature.

  Despite these limitations, alternatives that call for storage of cool water in the spring and later release of that water in the summer would be the most efficient in terms of water temperature.

  The above statement does not apply to meeting in–reservoir water temperature requirements of resident fish. In this regard, reservoirs that can be operated to create and subsequently release water at temperatures matching natural inflow temperatures as much as possible would best benefit resident fish.
- Total dissolved gas saturation is directly related to the amount of spill. Forced spill is always possible, especially during high water years, since projects have fixed hydraulic capacities.

Currently there are no real substitutes for voluntary spill to improve fish passage so "voluntary spill" is essentially mandatory. The most efficient alternatives minimize spill during critical times to avoid systemwide dissolved gas supersaturation.

- Increases in sediment transport, and the turbidity which accompanies them, are unavoidable when the pool elevations decline deeply enough into reservoir storage, when sediments have to be flushed out through the lower outlets of the dams, or when bank and mud flats are eroded through wind and wave action. Alternatives which call for stable high pool elevations, or at least a slow rate of pool change, are most efficient in controlling sedimentation. Speeding up refill of drawdown Lower Snake River reservoirs by augmenting flows specifically for this purpose could reduce streambank erosion by limiting the duration of exposure to storm events. The sooner the pool elevation is back up to the riprap level, the better.

### 4.3.5 Short–term Versus Long–term Perspectives

The altered condition of water, impacted by natural processes or altered naturally or by human action, tends to persist as it moves downstream. This can result in cumulative effects but the time involved is usually a year or less. Exceptions can occur when adverse hydrometeorological conditions continue over a longer period of time. Short–term impacts are in most instances indistinguishable from long–term impacts for all practical purposes. Also, if short–term impacts are negative, adverse long–term impacts can be expected to follow suit.

Increased sediment loads from drawdown alternatives would be of longer duration. Erosion from wind and wave action on exposed areas would be relatively high for the first few years. It would eventually subside when a state of equilibrium is reached between erodible materials and the streamflow regimen.

Point and nonpoint sources of water pollution are also expected to increase over the longer term, as a result of increasing population and development. Orderly development and effective regulation will be required to confront this potential for degradation. Based on current efforts to strengthen the Clean Water Act and other regulatory developments, the System Operation review water quality group expressed cautious optimism.

### 4.3.6 Possible Conflicts

There are several water quality impacts involving different water quality parameters. Potential solutions have been identified in the list of recommendations arising from the screening work. By and large, these solutions can be implemented separately since each problem requires a different set of preventive or curative actions. Consequently, improving one water quality parameter is generally not expected to adversely impact another parameter.

Solving water quality problems could, however, present some conflicts with other uses of the water. Limiting reservoir pool fluctuations for example would limit erosion but would also make the desired increase in current velocity an unreachable objective. Limiting or doing away with spill for–fish–passage would stop voluntary spill operation but might also defeat the intended purpose of improving dam passage survival for juvenile fish. Drawdown to natural riverbed elevation stops all spill during that period but will cause very high suspended sediment concentration.

### 4.3.7 Mitigation Measures

Many of the operation–related solutions to water quality problems can only be mitigative in nature. Monitoring and control of releases as problems develop can reduce impacts, to the extent allowed by discharge volumes and timing required by the alternatives.

Judicious selection of the release ports may provide some water temperature mitigation. This operation is only feasible at dams equipped with selective withdrawal facilities, during a period when reservoirs exhibit thermal stratification. A fairly comprehensive temperature monitoring program is currently maintained throughout the Columbia River, in conjunction with dissolved gas monitoring.

Monitoring and subsequently reducing or distributing spill to other project areas may provide some relief for high dissolved gas saturation. Modifying or adding flip lips to spill bays to minimize deep plunging has had some success depending on the project location. These solutions are only effective over limited flow and elevation ranges. Assuring that maximum possible powerhouse loads are available during high flow periods would reduce the need for forced spill and associated total dissolved gas supersaturation.

Other operational and structural techniques are available, including rule curve change, inflow routing, concentrating flow through one gate, and use of selective withdrawal and pneumatic destratification systems and underwater dams. These techniques are described in more detail in Technical Exhibit C. Redesign and/or addition of flip lip deflectors have the highest potential for reducing dissolved gas saturation levels through structural means. Currently, of the fourteen dams included in the System Operation Review, Ice Harbor, John Day, The Dalles, and Libby Dams are without such a facilities because of adverse impacts on adult fish passage and other reasons. Under the Dissolved Gas Abatement Study initiated in mid–1994, the location and effectiveness of the existing flip lips in reducing gas supersaturation and the extent to which additional flip lips and other physical modifications to fish passage facilities would reduce cumulative gas levels further are being re–analyzed. The two–phase Study will address the cumulative effect that can be achieved by having flip lips on all fourteen dams in the Columbia River basin.

So far, the Dissolved Gas Abatement Study has produced among other things a preliminary report, Dissolved Gas Interim Letter Report prepared in December 1994. This document contains a description of the various spillway configurations at the lower eight Corps of Engineers dams, and outlines a few potential alternatives that could be taken to reduce elevated dissolved gas levels. The history of flip lip construction and activities taken by the Corps of Engineers in the dissolved gas abatement area has been provided to the Oregon Department of Environmental Quality in May 1994, along with a list of actions associated with spill. Because the efficiency of spillway deflectors is very site–dependent, a comparison of similar facilities in the Columbia system with those elsewhere in the nation and world has not been accomplished.

From an operational standpoint, the need to develop protocols for total dissolved gas measurements, including quality assurance/quality control guidance, is of the highest priority. These protocols are currently being developed.

Because of the perceived need for more spill to improve juvenile fish passage over mainstem Columbia and Snake Rivers dams, it is likely that there will be more discussion of the efficacy of the state and EPA total dissolved gas standard in the future. This is based on recent activities and debates that took place during 1994 about what are the "right" dissolved gas and spill levels with respect to fish survival. Monitoring is being intensively used to describe the spatial and temporal distribution of dissolved below projects as related to various alternatives, spill levels, and stream discharge levels. Efforts are also being extended to learn more about the temporal variability of outmigrating salmon and steelhead.

For bank erosion, mitigation is generally limited to existing erosion control, speeding up reservoir refill to avoid exposing unprotected shorelines, and slope stabilization measures. Water quality impacts could be minimized by lowering water levels as slowly as possible. Increased monitoring of potential and active slide areas could be conducted to prevent more serious problems.

Mitigation measures including operational modifications, structural improvements or additions, close real–time monitoring, and more comprehensive studies cannot be expected to fully solve all known problems because little flexibility exists in eradicating these problems at the source.

In final analysis, monitoring, enforcement of stricter regulations, selected operational and structural techniques, and combining different alternatives depending on the run–off conditions appear to be the only promising avenues left. To bridge knowledge gap, a multi–agency collaborative effort on baseline ecosystem monitoring proposal by the U.S. Geological Survey (and supported by EPA) deserves to be pursued. This would involve:

(1) calculation of water velocity distributions and dissolved gas under various drawdown conditions, and determination of the effects of water–velocity changes on juvenile salmon outmigration rates;

(2) determination of the distribution of water temperatures in selected reservoirs (e.g. John Day Reservoir) and the relationship to salmon survival,

(3) assessment of the effects of various land or water uses on water temperature, and assessment of the potential success of remediation options in improving salmon habitat conditions; and

(4) development of a Geographic Information System data base and streamflow information for ungaged watersheds.

In the System Operation review, sediment analysis was only done for system operating strategies involving drawdown. It was concentrated on the volume of transport because information about other effects of sediment on water quality is lacking. Despite the fact that funding for needed research is a continuing problem, it is recognized that the need for sediment monitoring is ever present. Sediment studies should include biological testing to assess actual or potential adverse effects of the sediment pathway. Gathering of data on conventional and toxic pollutants and the impacts of these pollutants on fish and wildlife and human health would also be an appropriate mitigative measure to be diligently pursued.

### 4.3.8 Unavoidable Adverse Effects

Unavoidable adverse effects are those that are beyond man's control or part of an unavoidable physical process. Because of physical project limitations in terms of location and active storage size, and the natural interplay of solar radiation and heat absorption and the water bodies, control over water temperature is fairly limited. As soon as cool water released from a project reaches ambient temperature (which will occur in a predictable manner depending on flow rate, channel geometry and vegetation cover, temperature gradient between air and water, and other climatic factors), further heating of the water parcels beyond the desired temperature is simply unavoidable.

Another example is bank erosion caused by reservoir fluctuations or high streamflows. Despite mitigation measures such as riprap and other forms of protection, some erosion and hence temporary turbidity increase is unavoidable. From the total dissolved gas saturation point of view, some increase in saturation is unavoidable for any spill level, given the height of the dams involved.

## Table 4–7. Predicted Percent Exceedence for DDT, Total Lead, and Silt

**Percent of the Time Predicted DDT (DDT+DDE+DDD) Concentration Exceeds 0.0004 μg/l**

| | Lower Granite | | Ice Harbor | | Priest Rapids | | John Day | |
|---|---|---|---|---|---|---|---|---|
| SOR ALT | 15 Year Average | 1st. Year Maximum | 15 Year Average | 1st. Year Maximum | 15 Year Average | 1st. Year Maximum | 15 Year Average | 1st. Year Maximum |
| 2a | 10 | 21 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5b | 28 | 42 | 17 | 29 | 0 | 0 | 0 | 0 |
| 6b | 16 | 24 | 1 | 8 | 6 | 0 | 6 | 0 |
| 6d | 17 | 24 | 0 | 0 | 0 | 0 | 0 | 0 |

**Percent of the Time Predicted TOTAL LEAD Concentration Exceeds 15 μg/l**

| | Lower Granite | | Ice Harbor | | Priest Rapids | | John Day | |
|---|---|---|---|---|---|---|---|---|
| SOR ALT | 15 Year Average | 1st. Year Maximum | 15 Year Average | 1st. Year Maximum | 15 Year Average | 1st. Year Maximum | 15 Year Average | 1st. Year Maximum |
| 2a | 25 | 35 | 1 | 8 | 7 | 33 | 1 | 4 |
| 5b | 41 | 44 | 35 | 41 | 7 | 29 | 1 | 8 |
| 6b | 25 | 42 | 9 | 24 | 7 | 29 | 1 | 8 |
| 6d | 27 | 42 | 1 | 8 | 0 | 0 | 0 | 0 |

**Percent of the Time Predicted SILT Concentration Exceeds 25 μg/l**

| | Lower Granite | | Ice Harbor | | Priest Rapids | | John Day | |
|---|---|---|---|---|---|---|---|---|
| SOR ALT | 15 Year Average | 1st. Year Maximum | 15 Year Average | 1st. Year Maximum | 15 Year Average | 1st. Year Maximum | 15 Year Average | 1st. Year Maximum |
| 2a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5b | 25 | 36 | 23 | 36 | 0 | 0 | 0 | 0 |
| 6b | 5 | 17 | 3 | 21 | 0 | 0 | 0 | 0 |
| 6d | 5 | 17 | 0 | 0 | 0 | 0 | 0 | 0 |

NOTE: From DDt, total lead and silt, SOS 2a is equivalent to 2c.

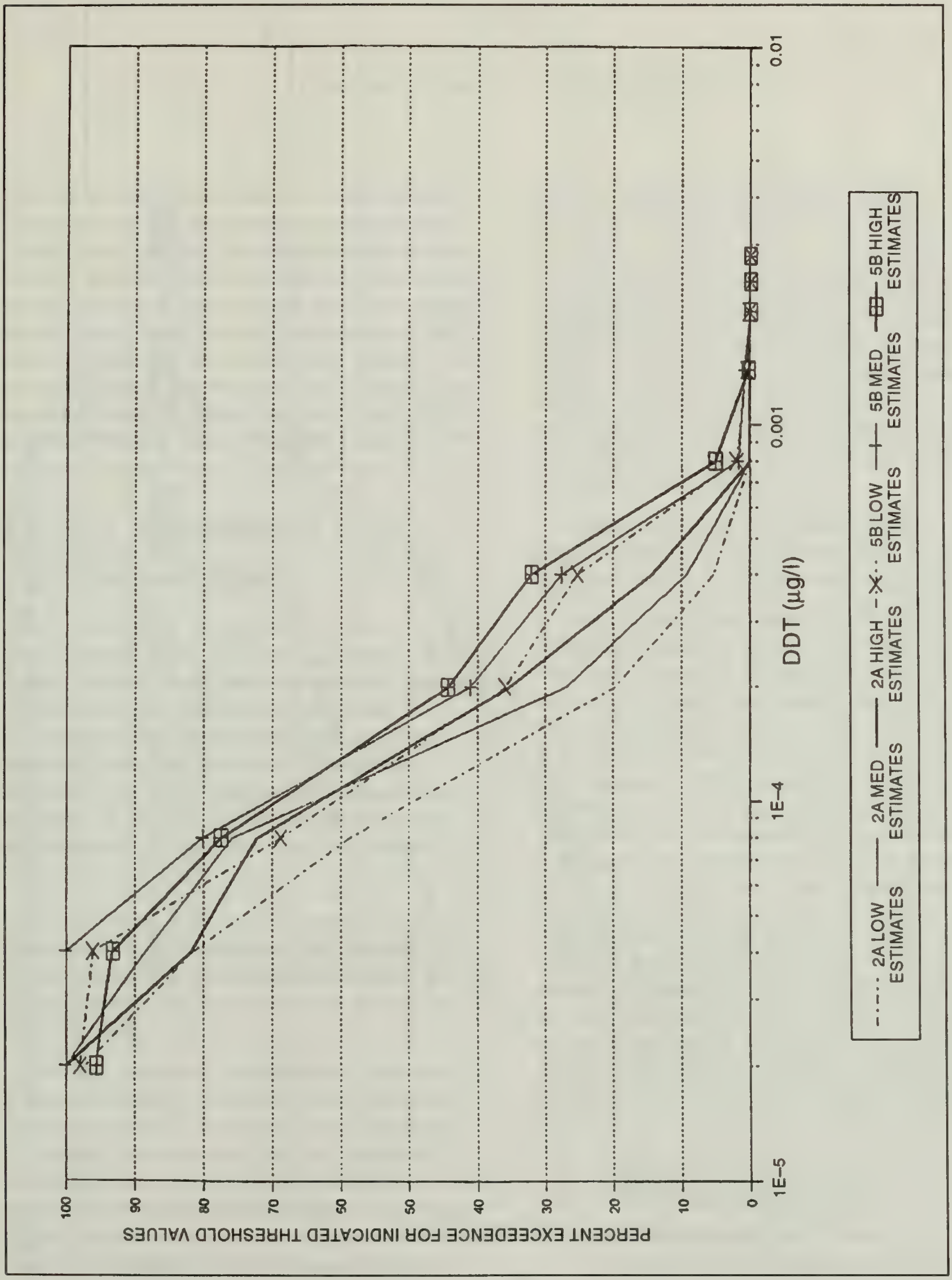


**Figure 4–10.** Predicted Percent Exceedence for DDT – Lower Granite (CP 50)

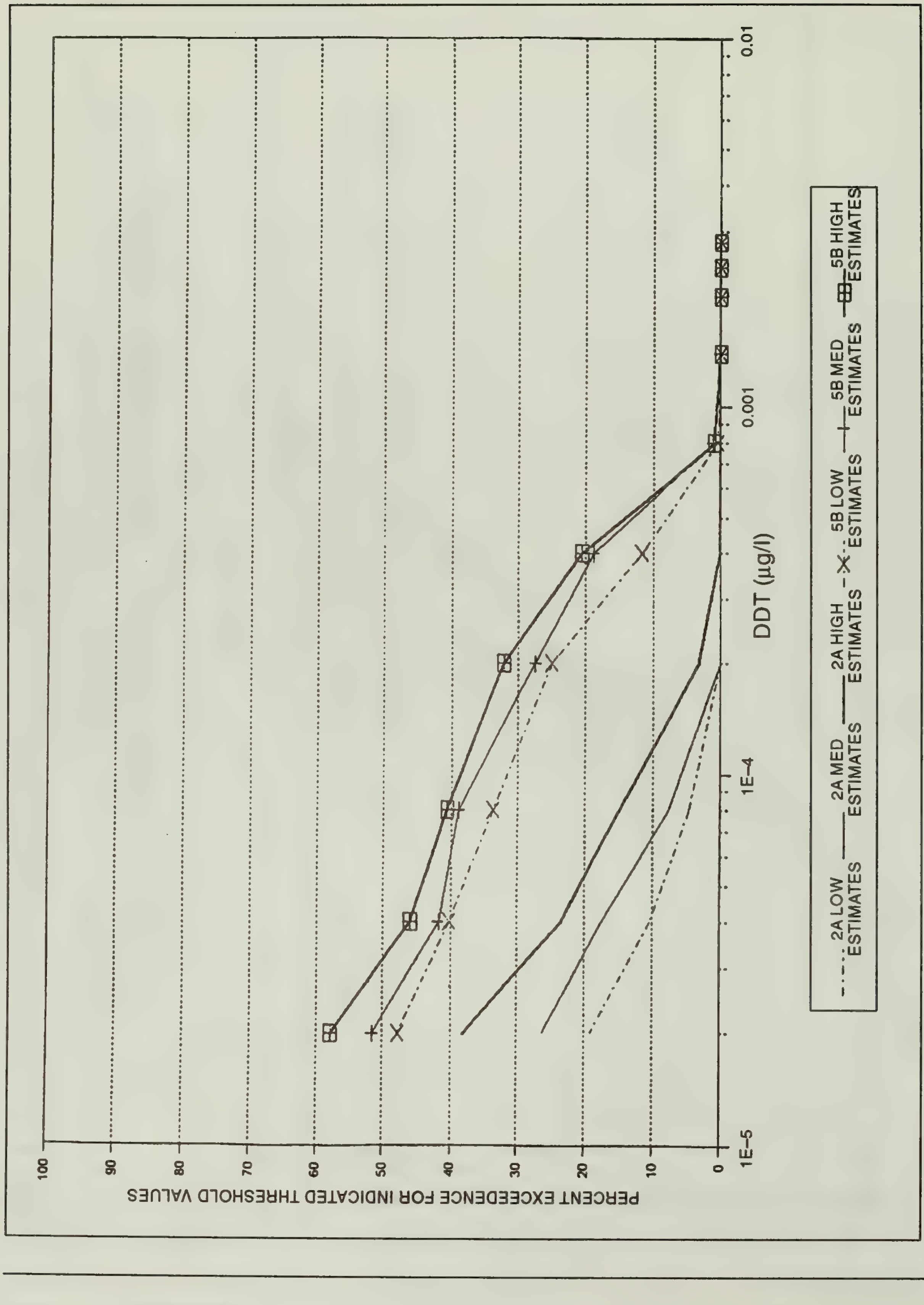


Figure 4–11. Predicted Percent Exceedence for DDT – Ice Harbor (CP 80)

# CHAPTER 5

# COMPARISON OF ALTERNATIVES

The impact of SOR alternatives on water temperature, total dissolved gas saturation, and sediment erosion were evaluated in detail. For water temperature, the number of days 17.2 degrees C was exceeded was established as a threshold; for dissolved gas, the number of days three levels of saturation were exceeded (110, 120, and 130 percent). Sediment was assessed by predicting the amount of material which would be transported given the operations called for in each alternative. Lead, DDT, and ammonia were evaluated against selected threshold values.

## 5.1 BASIS FOR COMPARISON

### 5.1.1 Comparison Criteria

Ideally, alternatives would have been ranked in terms of a total score, one including all three of the primary considerations, water temperature, dissolved gas, and sediment transport. But the effect of an alternative on any one of these parameters was no index of its effect of the others. An alternative calling for operations which benefitted water temperature, for example, did not necessarily reduce total dissolved gas saturation levels or sediment transport.

It was difficult to determine how much a given increase in dissolved gas offsets the advantage of lower temperature. The implications of other interactions between the three parameters are also not well established.

Rather than producing an unavoidably subjective composite ranking, alternatives were rated in terms of how they affected each of the three parameters separately. Performance indices are defined in Chapter 3 and numerical values in Chapter 4. Summary tables in Exhibit D were compiled from these results, using Alternative 2C as base case. The actual number of days when thresholds were exceeded is given for the base case, the number of days greater or less than this figure is given for other alternatives.

Results include the average, maximum, and minimum number of days thresholds are exceeded. State standards for water temperature vary between 13 and 20 degrees C (55 and 68 degrees F), depending on the state with jurisdiction, base temperature, streams, and time of the year. The 17.2 degrees C threshold was used because temperatures higher than this level are thought to impair the reproductive success of anadromous fish.

The state standard for total dissolved gas is 110 percent saturation. This saturation level, as well as two other greater levels, were used as thresholds.

A range of high to low water years was used for impact assessment –– five years for water temperature, and six years for total dissolved gas. The five years used for water temperature were: 1929 (low), 1959 (medium high), 1962 and 1973 (medium low), and 1974 (high). For total dissolved gas simulation, 1938 (medium), 1959 (medium high), 1962 and 1973 (medium low), 1974 (high), and 1977 (low) were used. These years were used to ensure than the predicted maximum and minimum pool elevations are reached at least once in all 21 alternatives.

The number of days the selected thresholds were exceeded at all the stations included in the models provided an indication how alternatives would perform under specific water conditions. "Numbers of days exceeded" are quantified data. The following steps were then used to go from the quantified data to indices of overall impact and qualified summary classifications:

a. list the number of "exceedence days" for each alternative and each year;

b. for each year, group alternatives in 3 or 4 categories depending on the spread between the lowest and highest values of the "exceedence days". For the most part, model predictions were not considered accurate enough to justify 21 separated ranking positions;

c. assign a numerical rating to each group. Alternatives with the lowest "exceedence days" should be in Group 1 and assigned a rating of 1. Conversely, alternatives with the highest number of "exceedence days" should be in the last group, and receive a rating of 3 (or 4). There is some degree of subjectivity in this assignment;

d. for each alternative, calculate the sum of the numerical rating values for all 5 or 6 years used in the analysis;

e. assign numerical indices of overall impact based on the total numerical rating values and the following scale that reflects predicted improvement or worsening of water temperature or total dissolved gas relative to the no change alternative (base case):

−2 = worst
−1 = worse
0 = no change (from the base case)
1 = better
2 = best

By definition, the index of overall impact for Alternative 2c was assigned a value of 0, regardless of its multi−year numerical rating. Indices for other alternatives vary between −2 and +2, depending on the difference between their multi−year numerical rating and the multi−year numerical rating of Alternative 2c.

There was an additional step in the analysis of total dissolved gas. First, indices of overall impacts were assigned separately as outlined above for the 110, 120, and 130 percent saturation thresholds. The final indices of overall impact were then calculated as weighted sums of the individual indices for 110, 120 and 130 percent saturation levels. A heavier penalty, in the form of greater weight, was given to alternatives that produced days in excess of the higher thresholds (1.0 for 110 percent, 1.5 for 120 percent, and 2.0 for 130 percent saturation).

For lead, DDT, and ammonia, the thresholds selected also did not necessarily coincide with water quality standards. The exceedence threshold is 15 μg/l for lead, 0.0004 μg/l for DDT, and 0.1 mg/l for ammonia. They are water column total concentrations. Generally, the thresholds are below water quality standards. The standards for lead and ammonia are dependent on other factors that vary within the system, and over time. The EPA standard for lead (based an average hardness in the Columbia River of 57 mg/l) is 25 μg/l, and for ammonia (based on an average water temperature of 59 of (15 °C), and a pH of 8.0) is 0.75 mg/l $NH_3+NH_4$. The standard for DDT is 0.001 μg/l. The DDT threshold is actually below current detection limits.

### 5.1.2 Alternatives Comparison

The results of alternatives comparison, based on the criteria outlined above, are provided in the following tables.

**Comparison Based on Water temperature**

Most changes in lower Snake River water temperature were attributable to releases of cool water from Dworshak Reservoir. Some changes also occurred in mid−Columbia and mid−Snake River reaches during those years when Grand Coulee and Brownlee Reservoirs were full and thus had a large volume of cool water in storage. As expected, elevated temperatures are most frequent during low flow years. For the same alternative, in average and high flow years, that potential is slightly reduced. This is the combined result of ambient temperature and the way the Columbia River System is regulated during those years for the alternatives under consideration.

Alternatives that caused (1) the most improved, and (2) the most degraded water temperature conditions in low (1929), average (1962), and high (1974) flow years are listed below. Both the absolute and relative numbers of days water temperature was predicted to exceed the given thresholds are given. Bracketed values refer to changes from the base case; and the number of days applies to all 20 sites for which daily water temperature predictions were made.

Low Flow, 1929 (days exceeding the threshold for the base case = 65.8)

Best 2: 6b = 63.3 (−2.5), 6d = 65.7 (−.1)

Worst 3: 9a = 73.4 (7.6), PA = 72.5 (6.7), 9b = 72.0 (6.2)

Average flow, 1962 (days exceeding the threshold for the base case = 68.2)

Best 3: 5b = 63.3 (−4.9), 6d = 67.0 (−1.2), 6b = 67.4 (−0.8)

Worst 3: 9a = 73.6 (5.4), PA = 72.8 (4.6), 9b = 72.7 (4.5)

High Flow, 1974 (days exceeding the threshold for the base case = 69.6)

Best 3: 5b = 65.2 (−4.3), 1a = 68.0 (−1.6), 1b = 68.7 (−.9)

Worst 3: 9c = 74.5 (4.9), 9a = 74.5 (4.9), 9b = 74.05 (4.4)

A plot showing the variation of the water temperature performance index for each flow year and each alternative is given on Figure 5−1.

**Table 5–1. Comparison Based on Average Number of Days Exceeding 17.2 °C Water Temperature Per Station – Individual Years**

| RUN−OFF CONDITIONS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Low 1929 | | Med.Low 1962 | | Med.Low 1973 | | Med.High 1959 | | High 1974 | |
| | Alt | Exc | Alt | Exc | Alt | Exc | Alt | Exc | Alt | Exc |
| 1 | 5b | 63.30 | 5b | 63.30 | 5b | 64.20 | 5b | 64.10 | 5b | 65.25 |
| 2 | 6d | 65.75 | 6d | 67.00 | 1b | 65.65 | 6d | 65.25 | 1a | 68.00 |
| 3 | 2c | 65.85 | 6b | 67.40 | 6d | 66.95 | 6b | 65.40 | 1b | 68.70 |
| 4 | 6b | 66.15 | 2c | 68.25 | 6b | 67.45 | 1b | 65.60 | 6d | 69.30 |
| 5 | 1b | 67.65 | 1a | 68.30 | 1a | 67.70 | 1a | 65.80 | 2c | 69.55 |
| 6 | 5c | 68.45 | 1b | 68.30 | 2c | 68.40 | 2c | 66.85 | 6b | 69.60 |
| 7 | 1a | 69.00 | 5c | 68.95 | 5c | 69.40 | 5c | 67.80 | 5c | 70.00 |
| 8 | 4c | 70.40 | 2d | 71.00 | 2d | 71.50 | 2d | 69.90 | 2d | 73.05 |
| 9 | 2d | 70.50 | 4c | 71.80 | 4c | 72.00 | 4c | 70.70 | PA | 73.50 |
| 10 | 9c | 72.05 | 9c | 72.35 | 9c | 72.60 | 9c | 70.95 | 4c | 73.85 |
| 11 | 9b | 72.10 | 9b | 72.70 | PA | 72.60 | 9b | 71.15 | 9b | 74.05 |
| 12 | PA | 72.55 | PA | 72.80 | 9b | 73.35 | PA | 71.70 | 9a | 74.50 |
| 13 | 9a | 73.40 | 9a | 73.65 | 9a | 77.30 | 9a | 72.80 | 9c | 74.50 |

### Table 5–2. Comparison Based Average Number of Days Exceeding 17.2 °C Water Temperature Per Station – All 5 Years Combined

| GROUPING FOR INDIVIDUAL YEARS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Alt | 1929 | 1962 | 1973 | 1959 | 1974 | All Yr. | Ind | Qualified Comments |
| 1 | 1a | 3 | 1 | 1 | 1 | 2 | 8 | 0.0 | No change |
| 2 | 1b | 2 | 1 | 1 | 1 | 2 | 7 | 0.7 | Better |
| 3 | 2c | 2 | 2 | 1 | 1 | 2 | 8 | 0.0 | No change |
| 4 | 2d | 4 | 3 | 1 | 1 | 4 | 13 | −1.6 | Worse |
| 5 | 4c | 4 | 4 | 1 | 1 | 4 | 14 | −2.0 | Worst |
| 6 | 5b | 1 | 1 | 1 | 1 | 1 | 5 | 2.0 | Best |
| 7 | 5c | 3 | 2 | 1 | 1 | 2 | 9 | −0.3 | Worse |
| 8 | 6b | 2 | 1 | 1 | 1 | 4 | 9 | −0.3 | Worse |
| 9 | 6d | 2 | 1 | 1 | 1 | 2 | 7 | 0.7 | Better |
| 10 | 9a | 4 | 4 | 1 | 1 | 4 | 14 | −2.0 | Worst |
| 11 | 9b | 4 | 4 | 1 | 1 | 4 | 14 | −2.0 | Worst |
| 12 | 9c | 4 | 4 | 1 | 1 | 4 | 14 | −2.0 | Worst |
| 13 | PA | 4 | 4 | 1 | 1 | 4 | 14 | −2.0 | Worst |

**Comparison Based On Total Dissolved Gas**

For total dissolved gas, comparison of alternatives was based on the total number of days exceeding the threshold of 110, 120, and 130 total dissolved gas saturation percent. High total dissolved gas saturation levels were mainly caused by heavy spill at Lower Snake River and McNary Dams. This usually resulted from high run−off that exceeds project hydraulic capacity, or from prescribed voluntary spill for fish migration. The number of days exceeding 110 percent saturation can change fairly drastically between a low and a high flow year.

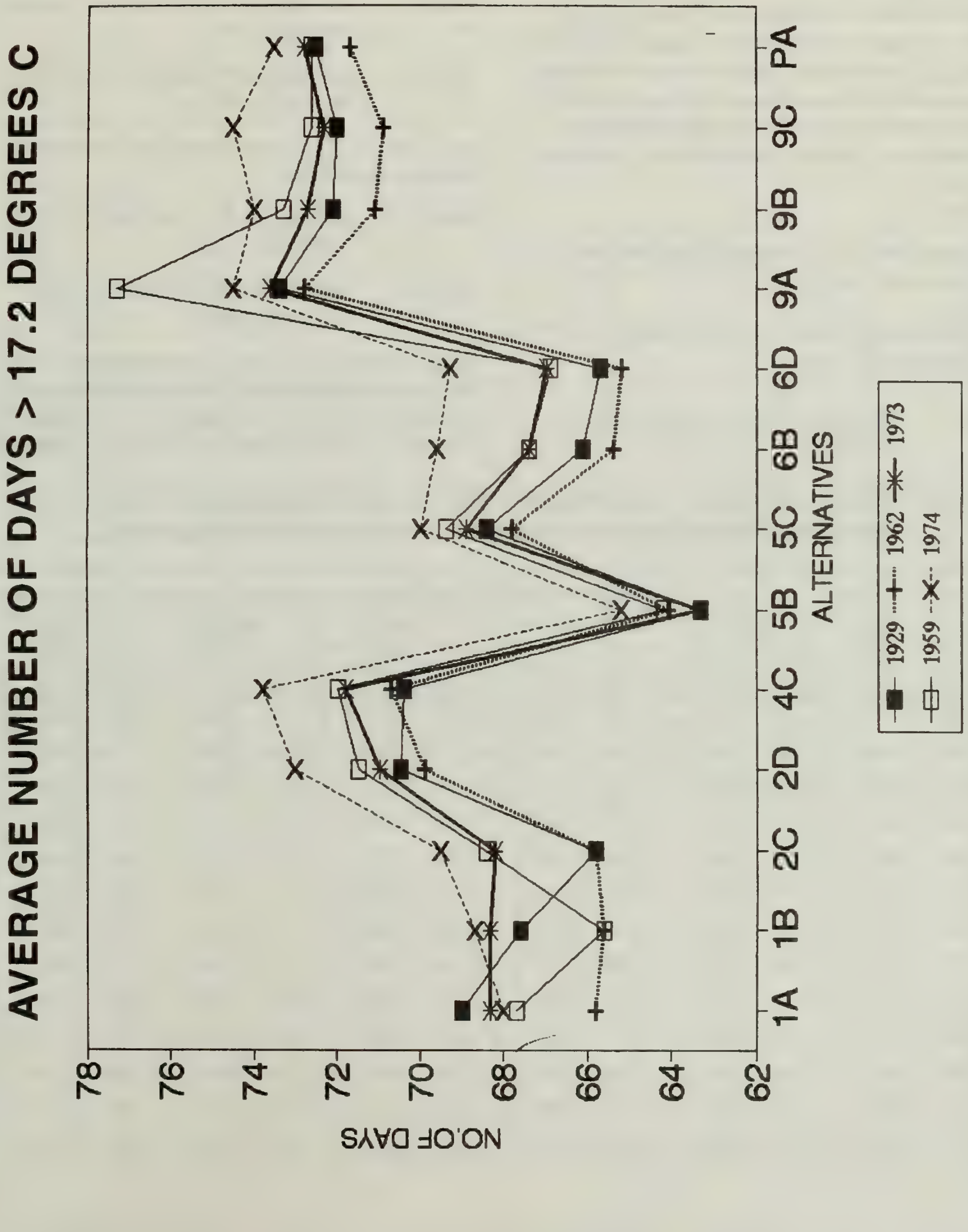


**Figure 5–1. Variation of Water Temperature Performance Index**

Alternatives that caused (1) the highest, and (2) the lowest total dissolved gas saturation conditions for a medium low (1973), medium high (1959), and high (1974) flow years are listed below. The difference between the number of days they exceeded the total dissolved gas threshold of 110 percent saturation and days exceeded in the base case is given in parenthesis. The number of days applies to all 14 sites for which daily total dissolved gas saturation predictions were made.

Medium low flow, 1973 (days exceeding the threshold for the base case =25.6)

| | |
|---|---|
| Best 3: | 2d=14.4 (−11.2), 5c=14.8 (−10.8), 4c=15.4 (−10.2) |
| Worst 3: | 9b=62.3 (+36.7), 9a=48.8 (+23.2), 9c=45.8 (+20.2) |

Medium high flow, 1959 (days exceeding the threshold for the base case=33.9)

| | |
|---|---|
| Best 3: | 5c=16.4 (−17.5), 5b=22.9 (−11.0), 4c=27.9 (−6.0) |
| Worst 3: | 9b=77.3 (+43.4), 9a=53.5 (+19.6), 9c=49.8 (+15.9) |

High flow, 1974 (days exceeding the threshold for the base case=73.2)

| | |
|---|---|
| Best 3: | 5b=56.5 (−16.7), 5c=56.5 (−16.7), 2d=56.8 (−16.4) |
| Worst 3: | 6d=73.8 (+0.6), 9a=83.4 (+10.2), 9b=91.6 (+18.4) |

Plots showing the variation of performance indices for total dissolved gas for each flow year and each alternative are given in Figures 5−2, 5−3, and 5−4 for 110, 120, and 130 percent saturation respectively.

**Table 5–3. Comparison Based on Average Number of Days Exceeding 110% Total Dissolved Gas Saturation per Station – Grouping for Individual Years**

| RUN−OFF CONDITIONS | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Low 1977 | | | Med. Low 1962 | | | Med. Low 1973 | | | Med. 1938 | | | Med.Hi 1959 | | | High 1974 | | |
| | Alt | Exc | Gr | Alt | Exc | Gr | Alt | Exc | Gr | Alt | Exc | Gr | Alt | Exc | Gr | Alt | Exc | Gr |
| 1 | 5c | 14.8 | 1 | 5c | 15.4 | 1 | 2d | 14.4 | 1 | 5c | 15.5 | 1 | 5c | 16.4 | 1 | 5b | 56.5 | 1 |
| 2 | 5b | 15.8 | 1 | 5b | 16.8 | 1 | 5c | 14.8 | 1 | 5b | 18.5 | 1 | 5b | 22.9 | 1 | 5c | 56.5 | 1 |
| 3 | 2d | 16.0 | 1 | 2d | 16.9 | 1 | 4c | 15.4 | 1 | 2d | 19.0 | 1 | 4c | 27.9 | 1 | 2d | 56.8 | 1 |
| 4 | 4c | 16.9 | 1 | 4c | 17.2 | 1 | 5b | 15.4 | 1 | 4c | 21.8 | 1 | 6b | 29.2 | 1 | 4c | 59.9 | 1 |
| 5 | 6b | 20.9 | 1 | 6b | 24.0 | 1 | 6b | 19.9 | 1 | 6b | 27.6 | 1 | 1a | 30.5 | 1 | 9c | 66.0 | 2 |
| 6 | 6d | 23.4 | 1 | 6d | 27.7 | 1 | 6d | 24.1 | 1 | 1b | 30.4 | 2 | 6d | 31.8 | 2 | PA | 67.1 | 2 |
| 7 | 2c | 23.9 | 1 | 2c | 28.8 | 1 | 2c | 25.6 | 1 | PA | 30.8 | 2 | 1b | 33.6 | 2 | 1a | 68.7 | 2 |
| 8 | 1b | 24.8 | 2 | 1b | 29.0 | 2 | 1b | 25.9 | 1 | 1a | 30.9 | 2 | 2c | 33.9 | 2 | 1b | 69.1 | 2 |
| 9 | 1a | 27.9 | 2 | 1a | 29.1 | 2 | 1a | 26.0 | 1 | 2c | 32.5 | 2 | PA | 35.7 | 2 | 6b | 70.4 | 2 |
| 10 | PA | 33.6 | 2 | PA | 30.5 | 2 | PA | 31.1 | 2 | 6d | 33.2 | 2 | 2d | 37.6 | 2 | 2c | 73.2 | 3 |
| 11 | 9c | 44.9 | 3 | 9c | 46.6 | 3 | 9c | 45.8 | 2 | 9c | 45.4 | 3 | 9c | 49.8 | 3 | 6d | 73.8 | 3 |
| 12 | 9a | 48.9 | 4 | 9a | 56.4 | 4 | 9a | 48.8 | 2 | 9a | 57.5 | 4 | 9a | 53.5 | 3 | 9a | 83.4 | 4 |
| 13 | 9b | 58.6 | 4 | 9b | 66.4 | 4 | 9b | 62.3 | 4 | 9b | 65.1 | 4 | 9b | 77.3 | 4 | 9b | 91.6 | 4 |

**Table 5–4. Comparison Based on Average Number of Days Exceeding 110% Total Dissolved Gas – Grouping for All 6 Years Combined.**

| ................................... RUN–OFF CONDITIONS ................................... | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Alt | Low 77 | Md.Lo 62 | Md.Lo 73 | Md. 38 | Md.Hi 59 | Hi 74 | All Yr | Ind Grp | Qualified Comments |
| 1 | 1a | 2 | 1 | 1 | 2 | 1 | 2 | 9 | 0.8 | Better |
| 2 | 1b | 2 | 2 | 1 | 2 | 2 | 2 | 11 | 0.0 | No change |
| 3 | 2c | 1 | 2 | 1 | 2 | 2 | 3 | 11 | 0.0 | No change |
| 4 | 2d | 1 | 1 | 1 | 1 | 2 | 1 | 7 | 1.6 | Better |
| 5 | 4c | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 2.0 | Best |
| 6 | 5b | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 2.0 | Best |
| 7 | 5c | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 2.0 | Best |
| 8 | 6b | 1 | 1 | 1 | 1 | 1 | 2 | 7 | 1.6 | Better |
| 9 | 6d | 1 | 2 | 1 | 2 | 2 | 3 | 11 | 0.0 | No change |
| 10 | 9a | 4 | 3 | 2 | 4 | 3 | 4 | 20 | −1.4 | Worse |
| 11 | 9b | 4 | 4 | 4 | 4 | 4 | 4 | 24 | −2.0 | Worst |
| 12 | 9c | 3 | 3 | 2 | 3 | 3 | 2 | 16 | −0.8 | Worse |
| 13 | PA | 2 | 1 | 2 | 2 | 2 | 2 | 11 | 0.0 | No change |

## Table 5–5. Comparison Based on Total Dissolved Gas (120% Saturation Threshold) Grouping for Individual Years

| RUN–OFFCONDITIONS | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Low 1977 | | | Med. Low 1962 | | | Med. Low 1973 | | | Medium 1938 | | | Med. High 1959 | | | High 1974 | | |
| No. | Alt | Exc | Gr | Alt | Exc | Gr | Alt | Exc | Gr | Alt | Exc | Gr | Alt | Exc | Gr | Alt | Exc | Gr |
| 1 | 1a | 0.0 | 1 | 1a | 0.0 | 1 | 1a | 0.0 | 1 | 1a | 0.0 | 1 | 1a | 0.0 | 1 | 1a | 0.0 | 1 |
| 2 | 2c | 0.0 | 1 | 1b | 0.0 | 1 | 1b | 0.0 | 1 | 1b | 0.0 | 1 | 1b | 0.0 | 1 | 1b | 0.0 | 1 |
| 3 | 2d | 0.0 | 1 | 2c | 0.0 | 1 | 2c | 0.0 | 1 | 2c | 0.0 | 1 | 2c | 0.0 | 1 | 2c | 0.0 | 1 |
| 4 | 4c | 0.0 | 1 | 2d | 0.0 | 1 | 2d | 0.0 | 1 | 4c | 0.0 | 1 | 5b | 0.0 | 1 | 5b | 0.0 | 1 |
| 5 | 5b | 0.0 | 1 | 5b | 0.0 | 1 | 4c | 0.0 | 1 | 5b | 0.0 | 1 | 6b | 0.0 | 1 | 5d | 0.0 | 1 |
| 6 | 6b | 0.0 | 1 | 5c | 0.0 | 1 | 5b | 0.0 | 1 | 6b | 0.0 | 1 | 6d | 0.6 | 1 | 6b | 0.0 | 1 |
| 7 | 6d | 0.0 | 1 | 6b | 0.0 | 1 | 6b | 0.0 | 1 | 6d | 0.0 | 1 | PA | 0.9 | 1 | 6d | 8.5 | 2 |
| 8 | 1b | 0.2 | 1 | 6d | 0.0 | 1 | 6d | 0.0 | 1 | PA | 1.8 | 1 | 4c | 1.6 | 1 | PA | 12.4 | 3 |
| 9 | PA | 2.3 | 1 | PA | 0.4 | 1 | PA | 0.6 | 1 | 2d | 1.8 | 1 | 5c | 3.6 | 2 | 9a | 14.3 | 3 |
| 10 | 5c | 3.6 | 2 | 4c | 1.0 | 1 | 5c | 3.6 | 2 | 5c | 3.6 | 2 | 2d | 3.9 | 2 | 9c | 15.0 | 3 |
| 11 | 9c | 6.1 | 3 | 9c | 6.2 | 3 | 9c | 4.6 | 2 | 9c | 5.0 | 2 | 9c | 4.4 | 2 | 9b | 17.6 | 4 |
| 12 | 9a | 9.9 | 4 | 9b | 9.5 | 4 | 9b | 9.7 | 4 | 9b | 8.7 | 3 | 9b | 6.5 | 3 | 4c | 18.6 | 4 |
| 13 | 9b | 11.3 | 4 | 9a | 12.3 | 4 | 9a | 11.6 | 4 | 9a | 11.3 | 4 | 9a | 10.8 | 4 | 2d | 22.9 | 4 |

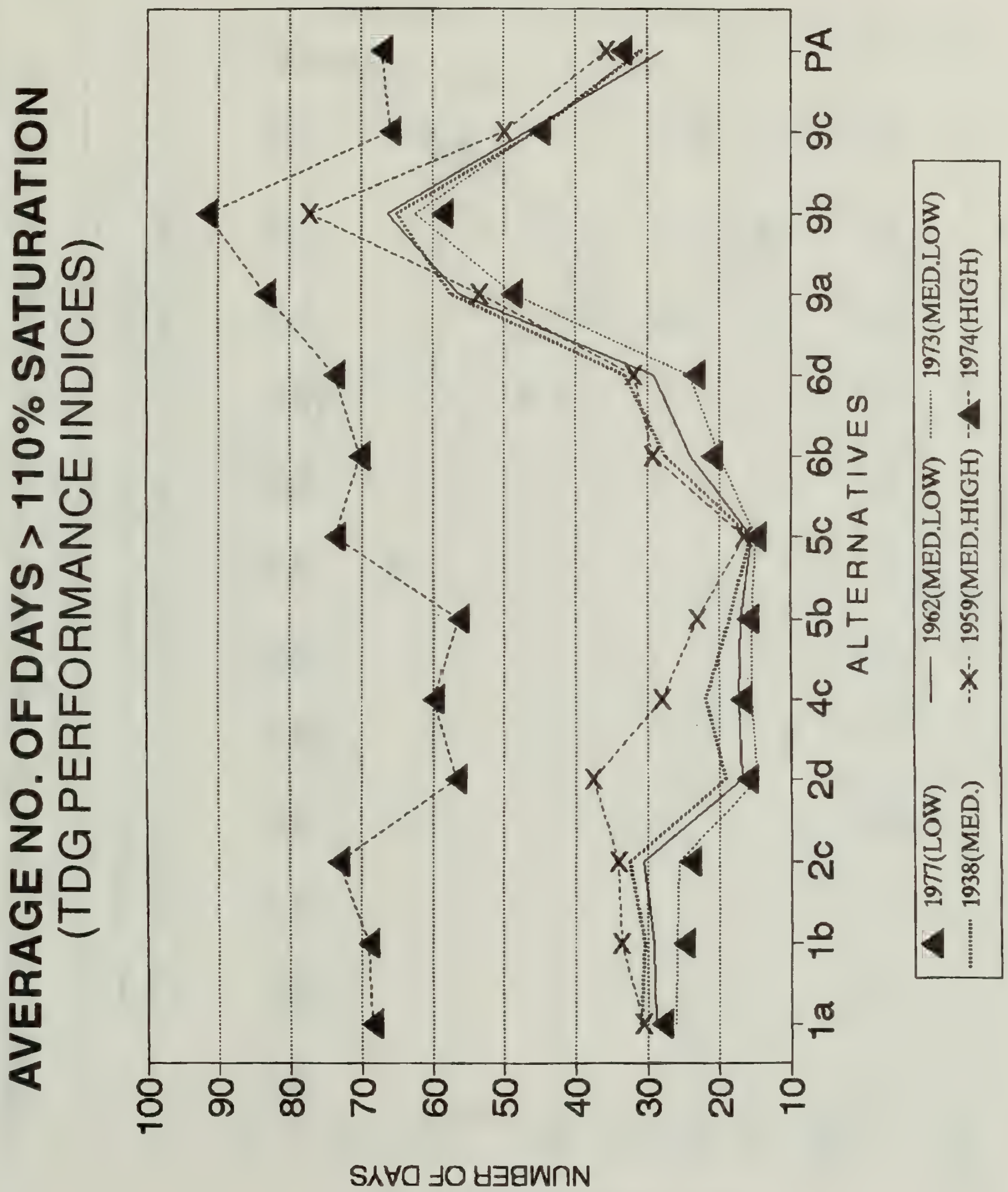


**Figure 5–2.** Variation of Total Dissolved Gas Performance Index, 110% Saturation

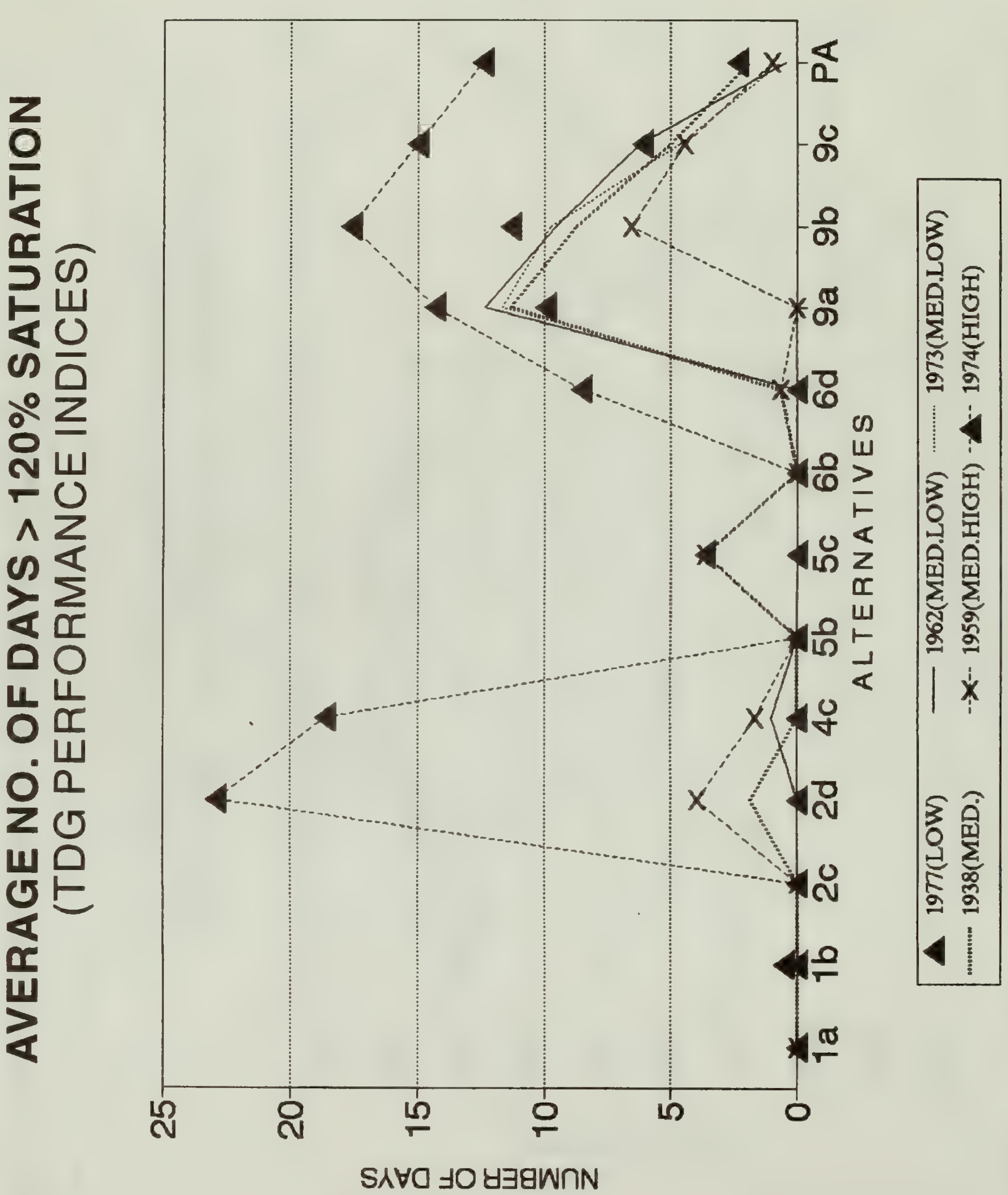


**Figure 5–3.** Variation of Total Dissolved Gas Performance Index, 120% Saturation

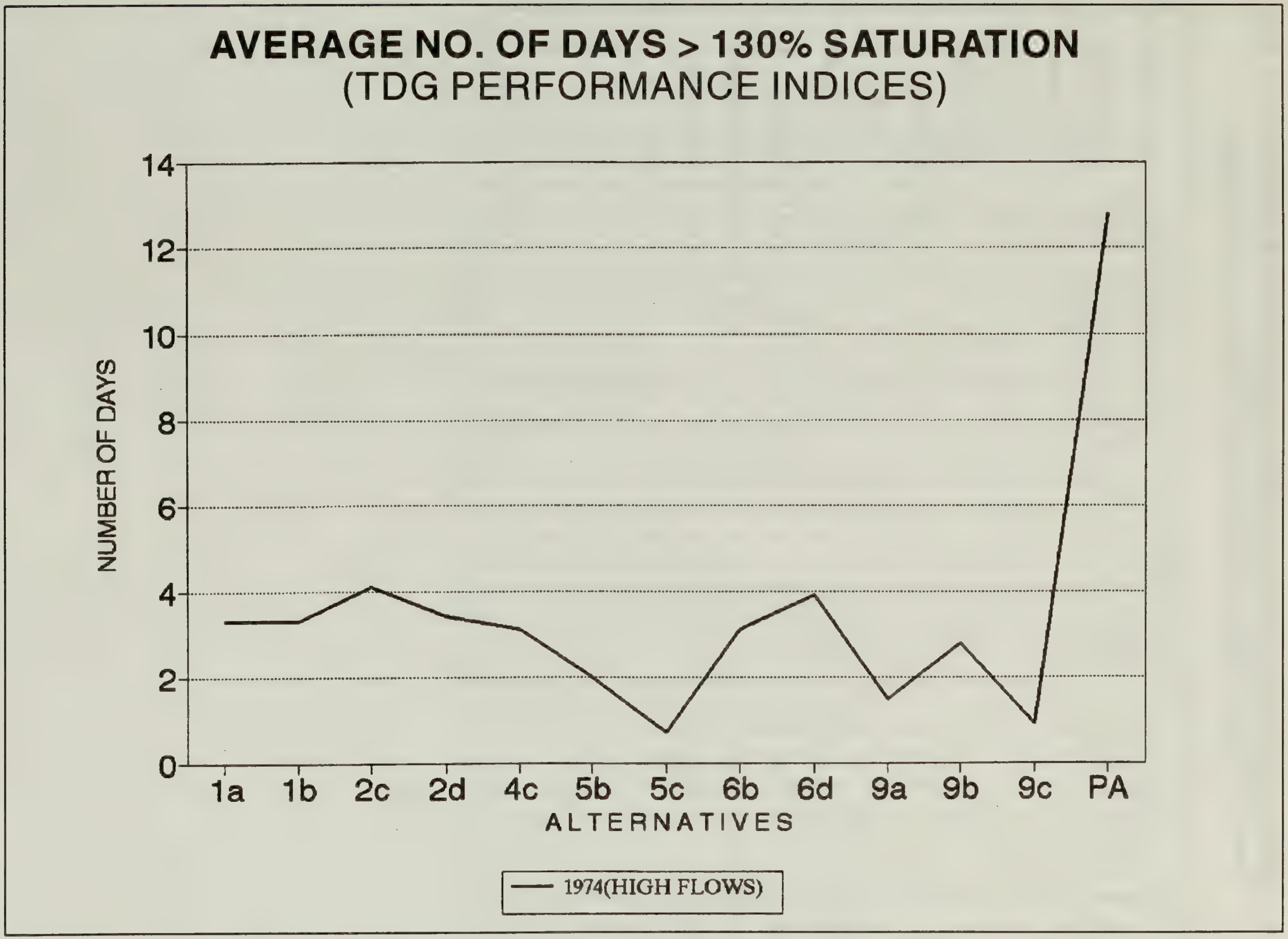


Figure 5–4. Variation of Total Dissolved Gas Performance Index, 130% Saturation

## Table 5–6. Comparison Based on Average Number of Days Exceeding 120% Total Dissolved Gas Saturation – All 6 Years Combined

| Run−off Conditions | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Alt | Low 1977 | Med.Low 1962 | 1973 | Medium 1938 | Med.High 1959 | High 1974 | All yrs. | Overall Index | Comments |
| 1 | 1a | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 0.0 | No change |
| 2 | 1b | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 0.0 | No change |
| 3 | 2c | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 0.0 | No change |
| 4 | 2d | 1 | 1 | 1 | 1 | 2 | 4 | 10 | −0.5 | Worse |
| 5 | 4c | 1 | 1 | 1 | 1 | 1 | 4 | 9 | −0. 4 | Worse |
| 6 | 5b | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 0.0 | No change |
| 7 | 5c | 2 | 1 | 2 | 2 | 2 | 1 | 10 | −0.5 | Worse |
| 8 | 6b | 1 | 1 | 1 | 1 | 1 | 1 | 6 | 0.0 | No change |
| 9 | 6d | 1 | 1 | 1 | 1 | 1 | 2 | 7 | −0.1 | No change |
| 10 | 9a | 4 | 4 | 4 | 4 | 4 | 3 | 23 | −2.0 | Worst |
| 11 | 9b | 4 | 4 | 4 | 3 | 3 | 4 | 22 | −1.9 | Worst |
| 12 | 9c | 3 | 3 | 2 | 2 | 2 | 3 | 15 | −1.0 | Worse |
| 13 | PA | 1 | 1 | 1 | 1 | 1 | 3 | 8 | −0.2 | No change |

**Table 5–7. Comparison Based on Average Number of Days Exceeding 130% Total Dissolved Gas Saturation Grouping for Individual Years**

| | ..................... RUN–OFF CONDITIONS .................... | | | | | | | | | | All 6Yrs Index | | | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | | Lo. 1977 | Md. Lo 1962 | Md. Lo 1973 | Md. 1938 | Md.Hi 1959 | | | Hi 1974 | | | | | |
| | Alt | Exc | Exc | Exc | Exc | Exc | Gr | Alt | Exc | Gr | Alt | Gr | Ind | |
| 1 | 1a | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 5c | 0.7 | 1 | 1a | 7 | 0.0 | No change |
| 2 | 1b | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 9c | 0.9 | 1 | 1b | 7 | 0.0 | No change |
| 3 | 2c | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 9a | 1.5 | 1 | 2c | 7 | 0.0 | No change |
| 4 | 2d | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 5b | 2.0 | 1 | 2d | 7 | 0.0 | No change |
| 5 | 4c | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 9b | 2.8 | 2 | 4c | 7 | 0.0 | No change |
| 6 | 5b | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 6b | 3.1 | 2 | 5b | 6 | 0.5 | Better |
| 7 | 5c | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 4c | 3.1 | 2 | 5c | 6 | 0.5 | Better |
| 8 | 6b | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 1a | 3.3 | 2 | 6b | 7 | 0.0 | No change |
| 9 | 6d | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | 1b | 3.3 | 2 | 6d | 7 | 0.0 | No change |
| 10 | 9a | 0.0 | 0.6 | 0.4 | 0.0 | 0.1 | 5 | 2d | 3.4 | 2 | 9a | 6 | 0.5 | Better |
| 11 | 9b | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 5 | 6d | 3.9 | 2 | 9b | 6 | 0.5 | Better |
| 12 | 9c | 0.0 | 0.1 | 0.0 | 0.0 | 0.1 | 5 | 2c | 4.1 | 2 | 9c | 6 | 0.5 | Better |
| 13 | PA | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 5 | PA | 12.8 | 4 | PA | 9 | −1.0 | Worse |

### Table 5–8. Comparison Based on Average Number of Days Exceeding 110, 120 and 130% Total Dissolved Gas Saturation – Indices of Overall Impact

| SATURATION % | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. | Alt | 130 | 120 | 110 | 130 | 120 | 110 | INDEX* | | |
| | (Weight: | 1 | 1 | 1 | 2 | 1.5 | 1) | Composite | Normalized | Comments |
| 1 | 1a | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | No change |
| 2 | 1b | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | No change |
| 3 | 2c | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 | No change |
| 4 | 2d | 0.0 | −0.5 | 1.6 | 0.0 | −0.75 | 1.6 | 0.85 | 0.6 | Better |
| 5 | 4c | 0.0 | −0.4 | 2.0 | 0.0 | −0.60 | 2.0 | 1.40 | 0.9 | Better |
| 6 | 5b | 0.5 | 0.0 | 2.0 | 1.0 | 0.00 | 2.0 | 3.00 | 2.0 | Best |
| 7 | 5c | 0.5 | −0.5 | 2.0 | 1.0 | −0.75 | 2.0 | 2.25 | 1.5 | Better |
| 8 | 6b | 0.0 | 0.0 | 1.6 | 0.0 | 0.00 | 1.6 | 1.60 | 1.0 | Better |
| 9 | 6d | 0.0 | −0.1 | 0.0 | 0.0 | −0.15 | 0.0 | −0.15 | 0.0 | No change |
| 10 | 9a | 0.5 | −2.0 | −1.4 | 1.0 | −3.00 | −1.4 | −3.40 | −1.4 | Worse |
| 11 | 9b | 0.0 | −1.9 | −2.0 | 0.0 | −2.85 | −2.0 | −3.85 | −1.5 | Worse |
| 12 | 9c | 0.5 | −1.0 | −0.8 | 1.0 | −1.50 | −0.8 | −1.30 | −0.5 | Worse |
| 13 | PA | −1.0 | −2.0 | 0.0 | −2.0 | −3.00 | 0.0 | −5.00 | −2.0 | Worst |

*normalized index between +2 and −2

**Comparison Based on Sediment Transport**

The amount of sediment transport in the Lower Granite Reservoir during the implementation of drawdown alternatives was indicated in Section 3.3 of Chapter 3. Using the HEC−6 model, estimations were made for the two and four and one half month versions of Alternatives 5b, 6c, and 6d. In each case, four levels of drawdown were addressed: minimum pool, 33 feet, 52 feet, and natural streambed. The 52 foot drawdown was part of the original study, but has since been withdrawn from consideration in the context of the System Operation Review.

Sediments transported past Lower Granite Reservoir onto other downstream reservoirs in the lower Snake and lower Columbia Rivers were also estimated, using HEC−5Q model. As stated in Chapter IV, estimates of sediment transport volumes for the newer alternatives introduced later in the System Operation Review were developed indirectly using a comparison of flow and drawdown specifications and identifying potential differences in Snake River velocity during drawdowns.

As expected, sediment transport was found to be directly related to the duration of the drawdown, its magnitude (depth), and to the number of reservoirs involved; the deeper and longer the drawdown, the more sediment transport. The length of shoreline and extent of mud flat areas exposed to erosion are a reflection of the number of reservoirs involved. The duration of the drawdown reflects the duration of the erosion process.

Impacts from drawdown are not measurable until pool elevations decline to or slightly below the minimum operating pool level. Currently, there is little sediment in the wind−wave zone to be transported and redistributed. Velocity changes in lowering reservoir pool from the normal full pool to this slightly lower operating range are also minimal.

Because of this direct and quantified relationship, ranking of alternatives in terms of sediment transport was comparatively straightforward. First, it was assumed that significant transport of sediment would not occur with System Operating Strategies Nos. 1, 2 and 4, which do not call for drawdown. The volume of sediment transport for those alternatives was assumed to be about the same, as represented by predictions made for alternative 2a. It was also concluded that a relatively small amount of sediment transport would occur with alternatives calling for operation at minimum pool.

Drawdown alternatives were then rated, based on predictions of the total volume of displaced sediment and turbidity at the mouth of the Snake River. The following ranking was made, moving from drawdown alternatives causing the least impact on sediment to those causing the most.

1. all nondrawdown alternatives
2. 6d (4 1/2 months, Lower Granite only, 33 feet down)
3. 6b (4 1/2 months, all 4 reservoirs, 33 feet down)
4. 5b (4 1/2 months, all 4 reservoirs to streambed)
5. 5c (permanent natural river operations year round)

**Comparison Based on Ammonia, Lead, and DDT**

The HEC−5Q model results showed no exceedence of the ammonia standard, and minor variation between the computed exceedences of the base case and drawdown alternatives.

The standard for DDT is 0.001 ug/l. The DDT threshold is actually below current detection limits. The DDT water column total concentrations being computed by the model are most likely coming from desorption of pollutants that have accumulated in the Snake River bottom sediments, after they get scoured into the water column during drawdown operations.

The model results for lead and DDT show the similar trends found for silt. Alternative 5b should generate the greatest lead and DDT exceedences of all the alternatives. Again, no significant departure from the base case is expected at the Columbia River locations – Priest Rapids and John Day Dams. The reduction in exceedence between alternatives 5b and 6a and 6b, and between Lower Granite and Ice Harbor Dams is also similar to that of silt.

The exceedence difference between the base case and the other drawdown alternatives at Lower Granite Dam is better shown by exceedence curves. At an exceedence threshold of 25 ug/l lead, the model shows an exceedence increase of about 25 percent for alternative 5b over the base case. This is closer to the silt trends expected at Lower Granite Dam. The trends in the computed exceedences indicate that lead and DDT accumulated in the Snake River sediments would be transported downstream with the sediments during drawdown operations.

For the natural river drawdowns, lead and DDT would deposit in Columbia River just downstream of the confluence with the Snake River. For the system operating strategy 6 alternatives, the lead and DDT would deposit in the partially drawn down pools. The process of desorption of the contaminants from sediment particles may produce a sediment cleansing effect, but it may also cause water quality standard exceedences in the water column.

**Comparison Summary**

The final comparison of alternatives for water temperature, total dissolved gas saturation and sediment transport is summarized in Table 5−9. Quantative predictions by models that have been calibrated for real−time Columbia River data provided estimates of how often selected thresholds values would be exceeded in each operating scenario. These quantified estimates were in turn translated in terms of qualified performance indices using an arbitrary rating scale. All performance indices are shown in relation to the base case and reservoir drawdown alternatives are indicated with an asterisk. A graphic display of the results is also provided in Figure 5−5.

As noted frequently in this discussion, alternatives often benefit one parameter of water quality at the expense of another. A recurring example involves water temperature and total dissolved gas. For the reason given above, it was impossible to identify a single alternative as preferable from the standpoint of water quality. Establishing a composite ranking of alternatives would involve assessments by other resources with water quality requirements, particularly anadromous and resident fish and recreation.

An attempt at an overall ranking was shown in Table 5–9, using a weighing coefficient of 2.0 for total dissolved gas, 1.0 for water temperature, and 0.5 for sediments. This weighing is based on the magnitude of the exceedences and relative prediction reliability.

**Table 5–9. Summary Comparison Based on Overall Performance Indices**

| No. | ........Performance Indices........ | | | | Composite Overall Ranking w/weight | ** Normalized Overall index | Alternative's Objectives |
|---|---|---|---|---|---|---|---|
| | Alt. (Weight: | Water Temp. 1 | Dissolv. Gas 2 | Sediment Transp. .5) | | | |
| 1 | 1a | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 1983–1991 operation |
| 2 | 1b | 0.7 | 0.0 | 0.0 | 0.70 | 0.1 | optimize power |
| 3 | 2c | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 | 1993 ops, fish flows |
| 4 | 2d | −1.6 | 0.6 | 0.0 | −0.40 | −0.1 | meet BiOp flow targets |
| 5 | 4c | −2.0 | 0.9 | 0.0 | −0.20 | 0.0 | stable storage w/ IRC |
| 6 | 5b | 2.0 | 2.0 | −2.0 | 5.00 | 2.0 | * 4.5 mo. natural river |
| 7 | 5c | −0.3 | 1.5 | −2.0 | 1.70 | 0.3 | * permanent natural river |
| 8 | 6b | −0.3 | 1.0 | −1.3 | 1.05 | 0.2 | * 4.5 mo. drawdown all reservoirs |
| 9 | 6d | 0.7 | 0.0 | −0.6 | 0.40 | 0.1 | * 4.5 mo. drawdown LWG only |
| 10 | 9a | −2.0 | −1.4 | −1.5 | −5.55 | −1.8 | DFOP flow targets at TDA |
| 11 | 9b | −2.0 | −1.5 | −1.3 | −5.65 | −1.9 | adaptive management |
| 12 | 9c | −2.0 | −0.5 | −1.0 | −3.50 | −1.2 | balanced impacts (Idaho Plan) |
| 13 | PA | −2.0 | −2.0 | 0.0 | −6.00 | −2.0 | support ESA recovery program |

(*) alternatives with drawdown (**) normalized between +2 and −2

Note: SOR 9 and PA received low rating for water temperature partly because of pool elevation constraints at Dworshak.

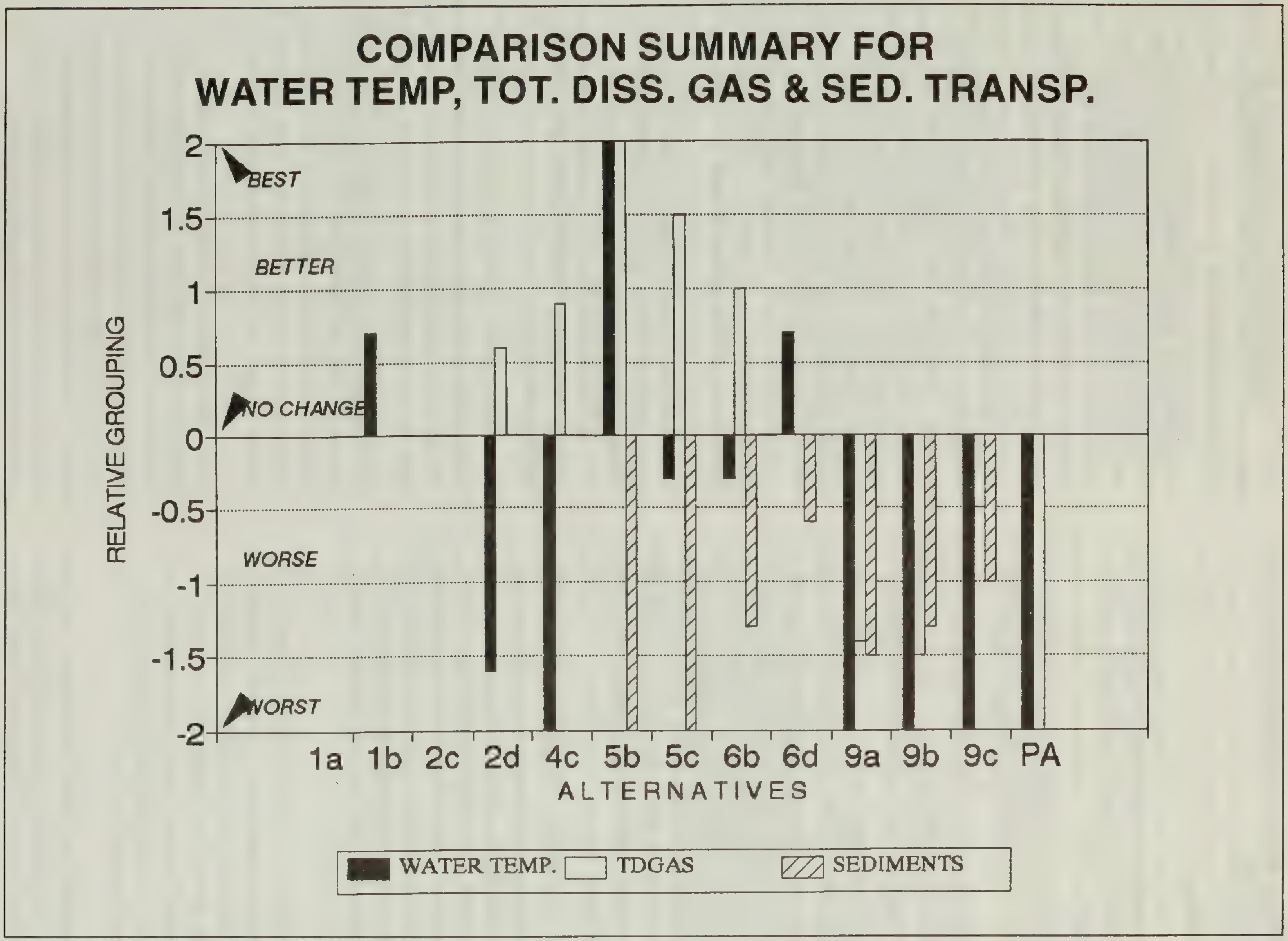


Figure 5–5. Comparison Summary for Water Temperature, Dissolved Gas, and Sediment Transport.

## 5.2 FINDINGS AND RECOMMENDATIONS FOR MITIGATION

### 5.2.1 Findings

All alternatives have some impact on water temperature, total dissolved gas and, to some extent, sediment transport.

Water temperature: alternatives which store the most cool water before the summer season are best.

Total dissolved gas: alternatives which produce the least amount of spill are best.

Sediment transport: alternatives which do not call for extreme fluctuations in reservoir elevations (and exposed riverbank and mud flat areas) are best.

But there physically is limited potential for controlling water temperature beyond a few tens of miles from deepwater storages. Eliminating spill would practically eliminate dissolved gas supersaturation problems, and maintaining current operations without severe drawdown would avoid creating bank and mud flats erosion, sediment resuspension and transport downstream.

None of the alternatives evaluated would require any more than the usual maintenance dredging for navigation. Effects of sediment resuspension under the Lower Snake River reservoir drawdown scenarios are also not expected to extend beyond McNary Dam. Sediment accumulation in Lake Wallula, due to Snake River drawdown operations, should be greatest during the first year, but diminish considerably after five years.

With the exception of total dissolved gas, most water quality conditions would not be seriously degraded if minimum flows below each dam were increased to improve the dilution and assimilation of various contaminants. Dissolved oxygen, which has not been a problem in the past, would also continue to be maintained at satisfactory levels.

Water temperature and total dissolved gas conditions were more favorable in the pre–Endangered Species Act alternatives than in the base case, but the differences were relatively slight. One has to go to the natural river options to see more visible improvements in those two areas.

The natural river options would be best for many water quality parameters under normal run–off conditions. There would be no impoundments to restrict flow, no structures producing spill, and reasonable assurance that minimum flows would be provided from headwater storage projects.

This return to natural river conditions, however, would generate a considerable amount of sediment transport at each dam down to and beyond the mouth of the Snake River. Turbidity from reservoir drawdown would be high, especially during the first few years of this type of operation. High turbidity could be harmful to fish and other aquatic fauna and flora and industrial and domestic water supplies. Erosion protection with armoring, riprapping and other conventional means would be cost–prohibitive given the length of shoreline affected.

More than one alternative may be required to provide optimum water quality conditions in the Columbia River Basin. Conceivably, this option could be built around the natural river alternative. Potential impacts on other water users would have to be taken into account.

Even within a given alternative, system regulation during extreme flow years may need to be different from that used in an average year, because of variability in water quality data.

The absence or insufficiency of information has been the main reason for shortcomings in this analysis. An improved understanding of whole river dynamics and processes is crucial to the formulation of solutions to current and future water quality problems.

Much information needed to provide a reliable prediction on the impacts of operations on many water quality parameters is missing. This includes data on cause–effect relationships between dams and reservoirs, pulp mills, and agriculture and water quality. There is a need to secure information and make existing data more generally available to the scientific community and concerned public.

### 5.2.2 Recommendations for Mitigation

The absence or insufficiency of information has been the mean reason for shortcomings in this analysis. An improved understanding of whole river dynamics and processes is crucial to the formulation of solutions to current and future water quality problems.

Research required to perform these holistic water quality studies should be given high priority. Of particular interest is further knowledge on sources, causes, transport, fate, and effects of contaminants. This involves: 1) knowing the source(s) of contaminants, what activities make the contaminants available, how they behave, where they end up, and to what extent contaminants cause ecological problems; 2) simulating the benefits of water quality mitigative measures; and 3) making it possible for management to have the information needed to make good ecological decisions.

While additional extensive studies and research may come too late for those fish and wildlife species that are threatened, deriving and implementing solutions without the best available data is also equally risky. Indeed, the need to expedite remedial actions has never been questioned. The basic research cited above was all identified by water quality professionals, many of whom fully support expeditious management plans.

Reservoir operations that cause water quality problems should be restricted. They include wide pool elevation fluctuations and spill that create or increase turbidity, heavy sediment transport, and high total dissolved gas saturation levels. Dworshak Reservoir should be stored with cool water that can be released later in the season to help reduce high water temperature in the lower Snake River.

The effect of water quality on fish and water supplies is crucial and priority should be given to mitigation measures protecting these resources. Examples include reducing the exposure of fish to warm, supersaturated, or turbid waters and securing alternative sources of water supplies during periods of adverse water quality conditions.

To improve water temperature control, selected deep reservoirs on the Columbia and Snake Rivers should be equipped with selective withdrawal facilities.

To minimize incidences of total dissolved gas supersaturation and continuing standard violations, installation of additional "flip−lip" structures should be investigated. Also, the construction of new and more efficient fish bypass systems should be explored. This would permit reducing spill now required to meet the 80 percent fish passage efficiency standard.

Water quality problems are caused by sources both internal and external to the streams. They must be resolved jointly by all interested and affected parties.

Communication with the public should be improved and more opportunities provided for public participation in system planning and management. Because the Columbia and Snake Rivers have to operate as a system for maximum overall benefit to the region, the public needs to have a better understanding of reservoir operating policies and limitations.

# CHAPTER 6

# LIST OF PREPARERS

## Table 6–1. List of Preparers

| Name | Education/Years of Exp. | Experience | Role |
|---|---|---|---|
| Bonneville Power Administration | | | |
| Linda Burbach | 14 years, BPA | Public Involvement<br>NEPA document processing | General Review<br>Contract Admin. |
| John Piccininni | B.A. Geography<br>M.A. Geography<br>19 years | Water Quality Planning,<br>Project/Program Mgmt. | Report Prep.<br>Techn. Review |
| Bureau of Reclamation | | | |
| David W. Zimmer | Ph.D. Limnology<br>M.S. Limnology<br>19 years | Water Quality & Pollution Control | Tech.Advisor and Reviewer |
| U.S. Army Corps of Engineers | | | |
| Richard A. Cassidy<br>Environ. Eng. | B.A. Biology<br>M.S. Zoology<br>M.S.Env.Engrg.<br>22 years | Aquatic Biology<br>Hydraulic Engrg.<br>Env.Engrg. | Water Quality Survey Analysis, Technical Review |
| Les Cunningham<br>Hydraulic Eng. | M.S. Civil Engrg.<br>22 years | Sediment Transport<br>Ice Engineering<br>Hydrology | Erosion & Sediment Transport Modeling |
| Tom Miller<br>Limnologist | M.S. Biological Sc.<br>BS Nat. Sc.<br>5 years | Aquatic Ecol.<br>Water Quality<br>Limnology | Modeling Tech. Advisor<br>Contract Admin.<br>Tech. Review |
| Glen Singleton<br>Hydr.Eng. | B.S.Civil Engrg.<br>9 years | Hydraulics<br>Water Quality | Water Quality Review<br>Modeling |
| Bolyvong Tanovan<br>Hydr.Eng. | Ph.D. Hydr.Engrg.<br>M.S. Civil.Engrg.<br>30 years | River Regulation<br>System Analysis<br>Water Quality<br>Computer Modeling | Work Group Coordinator: Modeling, Report Writing and Review |
| Nancy Yun<br>Hydr.Eng. | B.S. Industr.Engrg.<br>11 years | Modeling<br>Prog. Management | Modeling, Programming |
| U.S. Environmental Protection Agency | | | |
| William J. Sobolewski | B.S. Civil Engrg.<br>M.S. Sanitary Engrg.<br>Water Resources<br>32 years | Water Quality<br>Project/Program Management | Tech. Reviewer and Advisor |

**Table 6–1. List of Preparers – CONT**

| | | | |
|---|---|---|---|
| U.S. Geological Survey | | | |
| Stuart McKenzie | B.S. Physics<br>M.S. Civil Engrg.<br>Water Resources<br>30 years | Water Quality Data Collection/ Interpretation | Tech. Advisor<br>Reviewer |
| U.S. National Marine Fisheries Service | | | |
| Earl Dawley | B.S. Fisheries Sc.<br>25 years | Dissolved Gas and Salmonids Research | Tech.Advisor, Dissolved Gas and Fishery Impacts |
| Oregon Department of Environmental Quality | | | |
| William H. Young | B.A. History/Speech<br>17 years | Water Quality<br>Water Quality Management | Water Quality Review |
| Consultants | | | |
| Ebasco Environmental | | | |
| John Knutzen<br>Aquatic Scientist | M.S. Fisheries<br>Aquatic Biology<br>13 years | Aquatic Res.<br>Water Quality<br>Fisheries | Water Quality Analysis |
| Tom Martin<br>Environmental Consultant | Environment<br>13 years | Modeling | Ecological Modeling |
| Bruce Stoker<br>Geomorphologist | M.S.C.E.<br>M.S.Geology<br>B.S.Geology<br>14 years | Geology<br>Sediment Transp.<br>Hydrology | Water Quality Analysis |
| Independent | | | |
| Jack Berry | San Jose State University<br>25 years | Edited 15 NEPA documents for Fed.Govt. | Tech. Writer<br>Recorded proceedings and helped edit techn. appendix |
| Resource Management Associates | | | |
| Don Smith | B.S. Civil Engrg.<br>28 years | Water Quality & Sediment Transport Modeling | Computer Programming<br>Tech.Advisor on Model Application |

## CHAPTER 7

## GLOSSARY OF TERMS AND ACRONYMS

**Source:** The glossary of terms was mainly reproduced from the Glossary of Hydrologic Engineering Terms originally prepared by the US Army Corps of Engineers Hydrologic Engineering Center, Davis, California (July 1991). Acronyms are those found throughout the Appendix.

**Acid:** Most commonly refers to a large class of chemicals having a sour taste in water, ability to dissolve certain metals, bases or alkaline to form salts and to turn certain acid–base indicators to their acid form. Characterized by the hydrated hydrogen ion.

**Acre Foot:** A unit for measuring the volume of water––is equal to the quantity of water required to cover one acre to a depth of one foot and is equal to 43,560 cubic feet or 325,851 gallons.

**Advanced Water Treatment:** Renovation of used water by biological, chemical or physical methods that are supplied to upgrade water quality for specific reuse requirements. May include more efficient cleanup of a general nature or the removal of components that are inefficiently removed by conventional treatment processes.

**Advection:** The hydraulic mechanism by which water quality constituents are transported in the direction of the water flow.

**Aeration Period:** A theoretical time usually expressed in hours equal to the volume of the tank divided by the volumetric rate of flow.

**Aeration:** The process of adding air or other gases to, removing volatile constituents from, or mixing a liquid by intimate contact with air or other gases.

**Aeration Zone:** That portion of the lithosphere in which the functional interstices of permeable rock or earth are not (except temporarily) filled with water under hydrostatic pressure: that is, the interstices either are not filled with water or are filled with water that is held by capillarity.

**Aerobic:** Refers to life or processes occurring only in the presence of free oxygen; a condition characterized by an excess of free oxygen in the aquatic environment.

**Aggradation:** Raising of the stream bed due to settlement of moving sediment. This term is used for a "long term" e.g. several years) process. Contract with the term "deposition."

**Alga (pl. algae):** The simplest of all plant forms, having neither roots, stems, nor leaves. Algae range in size from microscopic single cells to branching forms one hundred feet or more in length. Usually aquatic, containing chlorophyll and capable of growth on mineral materials via energy from the sun. Algae forms the base of the food chain in aquatic environments. Some species may create a nuisance when environmental conditions are suitable for prolific growth. An algal bloom is a high concentration of a particular algal species; half of a million to one million cells per liter of water or more.

**Algorithm:** A rule or procedure for solving a logical or mathematical problem, frequently as incorporated into computer programs.

**Alkaline:** Water or soils which contain a sufficient amount of alkali substances present to raise the PH value above 7.0 or to be harmful to the growth of crops.

**Alkalinity:** 1. A term used to represent the content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates in water. It is expressed in mg/1 of calcium carbonate. 2. The acid combining capacity of a (carbonate) solution, expressed in milliequivalents (the number of cc. of tenth normal Hcl required to bring 100 cc of the solution being investigated to the methyl orange endpoint).

**Anadromous:** Pertaining to fishes that spend most of their life in salt water but enter freshwater to spawn; e.g., salmon, shad, striped bass, etc.

**Anaerobic:** A condition in which dissolved oxygen is not detectable in the aquatic environment. Commonly characterized by the formation of reduced compounds from the use of bound oxygen from sulfates, carbonates, or other oxygen–containing compounds as an hydrogen acceptor.

**Aquifer:** A subsurface water bearing unit that transmits water rapidly enough to supply useful quantities to springs and wells. Sand and gravel aquifers are characterized by innumerable spaces around and among the grains. Water is stored in and moves through those spaces. Limestone may have intergranular spaces but commonly stores and transmits water in small to cavernously large openings formed by solution. Lavas, especially basalt, store and transmit water in cracks and in boundary zones of rubble between successive flows of lava.

**Armoring:** The process of progressive coarsening of the bed layer by removal of fine particles until it becomes resistant to scour. The coarse layer that remains on the surface is termed the "armor layer." Armoring is a temporary condition; higher flows may destroy an armor layer and it may re–form as flows decrease.

**Assessment:** A legal financial obligation of the property owner in an irrigation, water, drainage or sanitary district, created for the purpose of financing the construction and operation of facilities required to protect and enhance public benefit within the district.

**Assimilation:** 1. Removal of dissolved or suspended materials from a water mass by biological, chemical and physical processes. 2. Conversion or incorporation of absorbed nutrients into body substances.

**Bacteria:** Primitive organisms having some of the features of plants and animals. Generally included among the fungi. Usually do not contain chlorophyll, hence commonly require preformed organic nutrients among their foods. May exist as single cells, groups, filaments, or colonies. Simple, colorless one–celled plants, most of which are unable to manufacture their own food using sunlight. Although some bacteria cause diseases, others fill an indispensable ecological role as decomposers. Aerobic bacteria require free (elementary) oxygen for their growth. Anaerobic bacteria grow in the absence of free oxygen and derive oxygen from breaking down complex substances.

**Bank Storage:** Water absorbed and stored in the voids in the soil cover in the bed and banks of a stream, lake, or reservoir, and returned in whole or in part as the level of the surface of the water body falls.

**Base Flow:** The sustained flow, contributed largely from groundwater, which apparently does not change materially during the duration of a flood. Usually arbitrarily estimated by connecting the low flow portion of the hydrograph before a flood to the slowly receding portion of the hydrograph after the flood when surface run–off has largely ceased.

**Basin (Watershed):** The region drained by one stream. Also a basin area separated from adjacent areas by ridges or mountain ranges.

Beach – The zone of demarcation between land and water of lakes, seas, etc.; covered by sand, gravel, or larger rock fragments.

**Bed Forms:** Irregularities found on the bottom (bed) of a stream that are related to flow characteristics. They are given names such as "dunes", "ripples", and "antidunes". They are related to the transport of sediment and interact with the flow because they change the roughness of the streambed. An analog to streambed forms are desert and dunes (although the physical mechanisms for their creation and movement may be different).

**Bed Layer:** An arbitrary term used in various procedures for computation of sediment transport. From observation of slow motion movies of laboratory flume experiments, H. Einstein defined the "bed layer" as: "A flow layer, 2 grain diameters thick, immediately above the bed. The thickness of the bed layer varies with the particle size."

**Bed Load:** 1. "Bed particles moving in the bed layer. Sand, silt, gravel, or soil and rock detritus carried by a stream on or immediately above its bed. The particles of this material have a density or grain size such as to preclude movement far above or for a long distance out of contact with the streambed under natural conditions of flow. This motion occurs by rolling, sliding, and sometimes by jumping." (H. Einstein). The term "saltation" is sometimes used in place of Einstein's "jumping." Bed load is bed material that moves in continuous contact with the bed; contrast with "suspended load." 2. Generally refers to the oxygen demand requirements of benthic deposits, sludge, muck, attached growths, moving materials, living or dead that are exerted upon waters as a result of bottom or boundary dynamics.

**Bed Load Discharge:** The rate at which bed load passes a particular point (cross section). Usually presented in units of tons per day. May be measured or computed.

**Bed Material Load:** The total rate (tons/day) at which bed material is transported by a given flow at a given location on a stream. It consists of bed material moving both as bed load and suspended load. Contrast with "wash load."

**Beneficial Use:** The use of water for some purpose from which benefits are derived. Such use includes domestic, irrigation, development of hydroelectric power, industrial, etc. The term benefits is variable with locality and custom, and what constitutes beneficial use is often defined by statute or in decisions of the court.

**Bioassay:** A test using a species of fish adaptable to laboratory conditions which consists essentially of preparing various concentrations of a waste with selected dilution and observing the reaction of the test fish over a definite time period. The fish which are used are normally fathead minnows or bluegill sunfish. The dilution water is normally water from the receiving stream into which the waste will be discharged.

**Biochemical oxygen Demand (BOD):** The quantity of oxygen utilized in the biochemical oxidation of non living organic matter by microorganisms, such as bacteria, in a specified time and at a specified temperature. It is not related to the oxygen requirements in chemical combustion, being determined entirely by the availability of the material as a biological food and by the amount of oxygen utilized by the microorganisms during oxidation. A high BOD may temporarily, or permanently, so deplete oxygen in water as to kill aquatic life. The determination of BOD is perhaps most useful in evaluating impact of wastewater on the receiving water bodies.

**Biodegradable:** A substance that is capable of being readily decomposed by biological means, especially by bacterial action.

**Blue–Green Algae:** A group of algae with a blue pigment, in addition to the green chlorophyll. A stench is often associated with the decomposition of dense blooms of blue–green algae in fertile lakes.

**BOD:** Abbreviation for Biochemical Oxygen Demand.

**Boundary Conditions:** The conditions around the spatial boundary of a problem area, which govern its solution. Here the forces applied at the receiving waters' boundaries, and the flows crossing them.

**Brackish Waters:** Those areas where there is a mixture of fresh and saltwater; or the salt content is greater than freshwater but less than seawater; or the salt content is greater than in seawater.

**Calibration:** The procedure of assigning values to the uncertain or unknown parameters in simulation model so predictions will correspond acceptably close to observed prototype behavior.

**Carrying Capacity:** The upper limit on the number of individuals of a particular kind of animal that can be supported within a given unit of habitat, such as an area of a stream.

**Celsius, Degrees (C):** A temperature scale based on one hundred equal division (degrees) between the freezing temperature of water (taken as 0 degrees C) and the sea–level boiling temperature (taken as 100 degrees C). Named for Anders Celsius, an 18th century Swedish astronomer who devised the scale.

**Centigrade:** A temperature measurement scale in which the freezing point of pure water as sea level is designated as 0 degrees C and the temperature of boiling water is designated as 100 degrees C. This is more properly termed the Celsius scale.

**Cfs:** Abbreviation of cubic feet per second.

**Channeling:** A condition in which certain portions of the flow within a channel or basin tend to seek a more limited distribution than that resulting from the confining bed or sidewalls, i.e., the flow may channel along the top, bottom or midchannel depth due to density, temperature, or some form of obstruction to uniform cross sectional flow.

**Chemical Oxygen Demand (COD):** The amount of oxygen required for the chemical oxidation of organics in a liquid. A quick (and only approximate) measure of loads of oxidizable matter in water. Results cannot be used interchangeably with BOD values. However, COD can quickly identify water with very low or very high BOD potential.

**Chemical Stratification:** A layering of water in a lake because of density differences owing to the varying or differential concentrations of dissolved substances with depth.

**Chlorination:** The application of chlorine to water or wastewater for the purposes of disinfection, oxidation, odor control, or other effects. Pre–chlorination – before treatment; post chlorination – after treatment; in–process chlorination – during treatment.

**Chlorine:** A greenish yellow gaseous element having strong disinfecting and oxidizing properties in water solution. It is commercially available as compressed gas, liquid, or in combined form as a powder. It is highly toxic and irritating to skin, eyes, and lungs in significant concentrations.

**Chlorine Demand:** The difference between applied chlorine and residual available chlorine in aqueous media under specified conditions and contact time. Chlorine demand varies with dosage, time, temperature, nature and amount of the water impurities.

**Chlorophyll:** Green photosynthetic pigment present in many plant and some bacterial cells. There are seven known types of chlorophyll; the green coloring material or pigment in plants that promotes the photo synthetic reactions forming organic materials form inorganic nutrients and light energy within the living cells.

**Coastal Waters:** Those waters surrounding the continent which exert a measurable influence on uses of the land and on its ecology. The great lakes and the waters to the edge of the continental shelf.

**COD:** Abbreviation for Chemical Oxygen Demand.

**Coliform Bacteria:** A large and varied group of bacteria. The fecal coliform bacteria flourish in the intestinal tract of warm blooded animals, including man. Escherichia coli ( E. coli) is largely of fecal origin and has been the indicator organism most commonly cited as indicating sewage or feedlot pollution. The coliforms apparently do not themselves cause disease, but their presence in water suggest that disease causing organisms (pathogens) may also be present.

Coliform bacteria are used as indicators of pollution because they are abundant and their presence is fairly easy to detect. The coli–aerogenes group is also among indicator organisms and is not usually distinguished from other fecal coliforms. Fecal streptococci and enteric viruses are pathogens found in animal waters. Methods for their identification in water remain provisional. The presence of fecal coliform bacteria suggests that streptococci and viruses may be present –– hence the concern over danger of infection whenever large numbers of fecal coliform bacteria are detected in water.

**Combined Sewage:** Consists of household, commercial or industrial wastes in combination with roof and surface storm drainage.

**Conservation Storage:** Storage of water for later release for useful purposes such as municipal water supply, power, or irrigation in contrast with storage capacity used for flood control.

**Constituent:** A physical, chemical or biological quantity whose presence in water is a factor in, or indicator of, water quality.

**Consumptive Use:** 1. Water absorbed by the crop and transpired or used directly in the building of plant tissue together with that evaporated from the cropped area. 2. Water transpired and evaporated from a cropped area or the normal loss of water from the soil by evaporated and plant transpiration. 3. Water discharged to the atmosphere or incorporated in the products of the process in connection with vegetative growth, food processing, or an industrial process.

**Convection:** 1. The meteorological phenomenon occurring where large masses of warm air, heated by contact with a warm land surface, and usually containing appreciable amounts of moisture, rise upward from the surface of the earth. 2. Movements of particles in a liquid as a result of changes in density.

**Correlation:** The process of establishing a relation between a dependent variable and one or more related independent variables. Correlation is simple if there is only one independent variable; multiple, if there is more than one independent variable.

**Cycle:** A regularly recurring succession of events such as the cycle of the seasons. Use of cycle to describe a group of wet years followed or preceded by a group of dry years is to be avoided.

**Daily (or Diurnal) Temperature Range:** The difference between the highest and lowest temperatures recorded on a particular day.

**Data:** Records of observations or measurements of facts, occurrences and conditions in written, graphical or tabular form.

**Dead Storage:** The volume in a reservoir below the lowest controllable level. Dead storage elevation is the lowest level at which it is practicable to release water from the reservoir, as governed by design of outlet facilities.

**Debris:** 1. The remains of something broken down or destroyed. 2. An accumulation of fragments of rocks.

**Decay:** 1. To undergo decomposition. 2. Implies a slow change from a state of soundness or perfection. 3. To decay.

**Decomposition:** The breakdown of dead plant and animal tissue by bacteria to the elemental state. Decomposers are living plants and animals, but chiefly fungi and bacteria, that live by extracting energy from the decaying tissues of dead plants and animals. In the process, they release simple chemical compounds stored in the dead bodies and make them available for use by green plants.

**Degradation:** 1. The geological process by means of which various parts of the surface of the earth are worn down and carried away and their general level lowered, by the action of wind and water. 2. Lowering of the streambed due the removal of bed material by the stream. This term is used for "long term" (e.g., several years) processes. Contrast with "scour."

**Dilution:** 1. To make thinner or more liquid. 2. A ration, volume or weight of a more concentrated sample or effluent flow compared to that into which it is discharged. 3. The reduction of a constituent concentration by mixing in water containing a lower concentration.

**Dissolved Oxygen (DO):** 1. The amount of free (not chemically combined) oxygen in water. Usually expressed in mg/l or percent of saturation. 2. DO concentration of unpolluted water depends pretty much on atmospheric pressure and temperature. Therefore, it is greater at sea level and when water is cool than at high altitudes or when water is warm. Nonliving organic matter (especially its content of carbon in any form) and various chemicals react with oxygen in water, depleting the oxygen and causing stress from lack of oxygen on fish and other aquatic life. In unpolluted water, oxygen is usually present in amounts of 10 ppm or more. Adequate dissolved oxygen is necessary for the life of fish and other aquatic organisms. About three to five ppm is the lowest limit for support of fish life over a long period of time. In extreme depletion, water may become anaerobic (literally without air), stagnate and stink.

**Dissolved Solids (DS):** The total amount of dissolved material, organic and inorganic, contained in water or wastes. Excessive dissolved solids can make water unsuitable for industrial uses, unpalatable for drinking, and even cathartic. Portable water supplies may have dissolved solids content from twenty to one thousand mg/l, but sources which have more than five hundred mg/l are not recommended by the U.S. Public Health Service. Also called Total Dissolved Solids and Total Solids.

**Drawdown:** The lowering of the surface elevation of a body of water, the water surface of a well, the water table, or the piezometric surface adjacent to the well, resulting from the withdrawal of water therefrom, i.e., the difference between the non-pumping water level at some time and the pumping level at that time. Drawdown storage capacity refers to storage space reserved for impoundment of run–off during some periods for the express purpose of retaining the water for later release when needed for industrial and municipal water supplies, irrigation, hydroelectric power generation, water quality improvement downstream, enhancement of downstream navigation, and other water uses. The same drawdown storage space may serve several of the water use objectives, provided the total space is large enough to regulate flows within acceptable provisions of scheduling; in such cases, the drawdown storage space is referred to as a "joint use" pool, and designated by design purposes involved.

**Ecology:** The study of the interrelationship of organisms among themselves and their environment.

**Entrainment:** A condition or action that will cause an immiscible substance to be mixed with another. Usually the result of turbulence or entrapment; i.e., air bubbles in aqueous media.

**Epilimnion:** The upper, relatively warm, circulating zone of water above the thermocline or metalimnion in a thermally stratified lake.

**Equilibrium:** The condition in which a population or community is maintained with only minor fluctuations in composition over an extended period of time.

**Erosion:** The general process or group of processes whereby the materials of the Earth's crust are loosened, dissolved, or worn away, and removed from one place to another by solution and transport due to water, wind, ice, and other natural forces. Weathering, although sometimes included here, is a distinct process which does not imply removal of any material.

**Eutrophic:** Lakes which are rich in nutrients and organic materials, therefore, highly productive, these lakes are often shallow and seasonally deficient of oxygen in the hypolimnion. (See Oligotrophic lakes)

**Eutrophication:** A natural process of the aging of lakes characterized by nutrient enrichment and increasing growth of plant and animal organisms. The net effect is to decrease depth until the lake becomes a bog and eventually dry land. Man–made pollution tends to hasten the proliferation of plant life due primarily to an excess of nutrients particularly nitrogen and phosphorus. Plant life grows in abundance as a result of incomplete treatment particularly from municipal wastes. (See Dystrophic, Mesotrophic, Oligotrophic)

**Exceedence Frequency:** The percentage or proportion of values that exceed a specified magnitude.

**Exceedence Interval:** The average interval of time between values that exceed a specified magnitude, reciprocal of the exceedance frequency.

**Exceedence Probability:** Probability that an event selected at random will exceed a specified magnitude.

**Extinction Depth:** The depth below a lake surface at which the light intensity is only one percent of its intensity at the surface.

**Fahrenheit, Degree (F):** A temperature scale in which freezing temperature of pure water at sea level is 32 degrees F and boiling is 212 degrees F. Named for Gabriel D. Fahrenheit, an 18th century German physicist.

**Fecal Coliform:** A group of organisms belonging to the coliform group and whose presence denotes recent fecal pollution from warm blooded animals. Standard tests are available to differentiate the fecal coliform group from the other members of the group which have a lesser sanitary significance. (See Coliform Bacteria)

**Fermentation:** A form of respiration by organisms which requires little or nor free oxygen, yielding alcohol and carbon dioxide as end products and releasing only part of the food energy available; i.e., the conversion of sugars into alcohol by enzymes from yeasts.

**Flocculation:** The gathering together of fine particulate materials in a suspension to form loosely associated larger masses of solids agglomerates.

**Forebay:** A reservoir or pond located at the head of the penstock of a hydroelectric powerplant, which is used to store water to care for variations in the electrical load.

**Gradation:** A measure of the variation in grain (particle) sizes within a mixture. Usually presented as a graph of grain diameter vs. percent of the mixture that is finer than that diameter.

**Green Algae:** Algae that have pigments similar in color to those of higher green plants. Some form produce algal mats or floating "moss" in lakes.

**Groundwater:** Subsurface water that completely fills (saturates) all available space within an aquifer and below the top of the zone of saturation. Contrast with water in unsaturated zone. Groundwater does not occur in subsurface "lakes" nor move in subsurface "rivers" except those in a few caves in limestone.

**Habitat:** The immediate surroundings (living place) of a plant or animal; everything necessary to life in a particular location except the life itself.

**Hypolimnion:** The cooler lower level of a thermally stratified body of water which extends from the metalimnion to the bottom and which is essentially removed from surface influence.

**Inorganic:** Being composed of material other than plant or animal materials. Forming or belonging to the inanimate world.

**Irrigation Efficiency:** The percentage of water applied that can be accounted for in soil moisture increase.

**Irrigation Requirement:** The quantity of water, exclusive of precipitation, that is required for crop production. It includes surface evaporation and other economically unavoidable wastes.

**Irrigation:** The controlled application of water to arable lands to supply water requirements not satisfied by rainfall. The irrigated area is the gross farm area upon which water is artificially applied for the production of crops, with no reduction for access roads, canals, or farm buildings.

**Leaching:** 1. The removal of soluble constituents from soils or other material by percolating water. 2. The removal of salts and alkali from soils by abundant irrigation combined with drainage. 3. The disposal of a liquid through a nonwater–tight artificial structure, conduit, or porous material by downward or lateral drainage, or both, into the surrounding permeable soil.

**Limnology:** The study of physical, chemical, and biological aspects of lakes.

**Local Scour:** Erosion caused by an abrupt change in flow direction or velocity. Examples include erosion around bridge piers, downstream of stilling basins, at the ends of dikes, and near snags.

**Low Flow Augmentation:** Increasing of an existing flow. The ability to assimilate waste can generally be improved by storage of flood flows and their subsequent release when natural flows are now and water quality conditions are poor.

**Mathematical Model:** The set of equations, usually based upon fundamental physical principles, that describe a physical process.

**Metalimnion:** The layer, in a thermally stratified body of water, for which the temperature difference is largest per unit of depth. This layer separates the epilimnion from the hypolimnion.

**Metamorphosis:** Abrupt transformation of an animal from one distinctive life history stage to another in its postembryonic development; e.g., larva of an insect to a pupa.

**Microorganisms:** These organisms retained on a U.S. standard sieve no. 100 (openings of 0.149 mm); those minute organisms invisible or only barely visible to the unaided eye. Microphytes are small plants.

**Mixing Zone:** An area where two or more substances of different characteristics blend to form a uniform mixture; i.e., chlorine application, heated water, or other discharged materials entering a water mass will show significant differences of chlorine residual, temperature or other criteria, depending upon the sampling location throughout the mixing zone and approach uniform results with respect to lateral, longitudinal, and vertical sampling positions when mixing has been completed.

**Movable Bed:** A streambed made up of materials readily transportable by the streamflow.

**Mudflow:** A well–mixed mass of water and alluvium which, because of its high viscosity and low fluidity as compared with water, moves at a much slower rate, usually piling up and spreading over the fan like a sheet of wet mortar or concrete.

**Natural Flow:** The flow resulting from natural hydrologic conditions. (Unaffected by man–made structures which would alter the natural regime).

**Nonconservative:** A constituent that may be subject to chemical, biological, or physical processes that tend to alter it or remove it from solution or suspension.

**Nonconsumptive:** Uses of water in which only a small part of the water is lost to the atmosphere by evapotranspiration or by combination with a manufactured product. Nonconsumptive uses return to the stream or the ground approximately the same amount as diverted or used.

**Normal Full Pool Elevation:** This term corresponds to the top reservoir level that would be attained for routine storage of water for flood control, hydroelectric power, low–flow augmentation, recreation, sediment control, or other authorized storage uses; this level corresponds to the "total design capacity" of the reservoir selected initially on the basis of planning and design studies, excluding surcharge storage that is provided primarily to reduce costs of constructing and maintaining the dam and appurtenances or to improve safety of operation during emergencies.

**Normal Year:** A year during which the precipitation or streamflow approximates the average for a long period of record.

**Numerical Model:** A numerical model is the representation of a mathematical model as a sequence of instructions (program) for a computer. Given appropriate data, the execution of this sequence of instructions yields an approximate solution to the set of equations that comprise the mathematical model.

**Nutrient:** 1. Any chemical element, ion, or compound that is required by an organism for the continuation of growth, reproduction, and other life processes. 2. Includes many combination elements and combinations of them. The major nutrients include carbon, hydrogen, nitrogen, sulfur, and phosphorus. 3. Nitrogen and phosphorus are of major concern because they tend to recycle and are hard to control.

**Oligotrophic:** Lakes which have a low supply of nutrients, thus they support very little organic production. Dissolved oxygen is present at or near saturation throughout the lake during all seasons of the year. (See Eutrophic Lakes)

**Outfall Sewer:** The outlet or channel through which sewage effluent is discharged.

**Oxygen Demand, Biochemical (Oxygen–Depleting Effect; BOD):** The amount of oxygen required for aerobic bacteria to oxidize completely the organic decomposable matter in water within a specified time and at a given temperature – an index to the degree of organic pollution in the water. When discharged to a watercourse, waste containing BOD constituents will consume dissolved oxygen in the water; the BOD indicates the amount of oxygen used up. Waters that receive high BOD waste undergo reduction of oxygen and consequent damage to aquatic life.

**Oxygen Depletion:** The loss of oxygen from water or sewage due to biological, chemical or physical action.

**Pesticide:** Any chemical preparation used to kill pests. Includes insecticides, herbicides, fungicides, etc.

**pH:** An index of hydrogen ion activity. Defined as the negative logarithm (base 10) of the hydrogen ion concentration at a given instant. On a scale of zero to fourteen, pH of 7.0 is neutral, pH less than 7.0 indicates a predominance of hydrogen ions (acid); pH greater than 7.0 indicates a lack of hydrogen ions (alkaline). The pH of most natural water falls within the range of four to nine. Slight decrease in pH may greatly increase the toxicity of pollutants such as ammonia. Alkaline water will tend to form a scale; acid water is corrosive.

**Phytoplankton:** The plants of the plankton. Unattached microscopic plants subject to movement by wave or current action.

**Plankton:** Suspended microorganisms that have relatively low powers of locomotion, or that drift in the water subject to the action of waves and currents.

**Pollution:** Contamination or other alteration of the physical, chemical or biological properties of water that renders it unacceptable in terms of established water quality standards or beneficial uses of the water, including changes in temperature, taste, color, or odor of the water, or the discharge into the water of any liquid, gaseous, radioactive, solid, or other substance that may create a nuisance or render such water detrimental or injurious to public health, safety or welfare. Broadly, pollution means any change in water quality that impairs it for the subsequent user.

**Pools:** The deepwater areas of a stream, where the velocity of current is reduced. The reduced velocity provides a favorable habitat for plankton. Silt and other loose materials that settle to the bottom of this zone are favorable for burrowing forms of benthos.

**Primary Treatment:** Commonly the separation of settleable or floatable materials from carrier water. Usually preceded by pretreatment such as coarse screens, grit separation, or comminution.

**Process:** A series of operations or actions that lead to a particular result. A combination of unit operations that may be assembled and used for a given treatment objective.

**Quality:** 1. For water, the composite chemical, physical, and biological characteristics of water with respect to its suitability for a particular use. 2. For snow, the fraction of the total weight of a snow sample which is in the form of ice, the remaining portion consisting of entrained liquid water.

**Radionuclide:** A radioactive atom having 1. a specified number of protons and neutrons (therefore a specified mass), and 2. the property of giving off protons, neutrons, or rays at a specified time rate.

**Regulation:** The artificial manipulation of the flow of a stream.

**Relative Humidity:** The ratio of the actual quantity of water vapor present in a small volume to the quantity of water vapor required for saturation at the same temperature. The percentage of saturation.

**Reregulating Reservoir:** A reservoir for reducing diurnal fluctuations resulting from the operation of an upstream reservoir.

**Reservoir:** A pond, lake, tank, basin, or other space, either natural in its origin, or created in whole or in part by the building of engineering structures, which is used for storage, regulation, and management of water.

**Reservoir Pool Elevation:** Water Surface elevations in the reservoir near the dam site, exclusive of wave action and wind– tide effects.

**Reservoir Storage Space:** Reservoir capacity available between two flat pool elevations as indicated by appropriate elevation– capacity curves.

**Reservoir–Type (Flow–Storage) Curve:** A curve showing the relation between simultaneous values of storage and outflow. Used in routing flows through a reservoir of short river reach.

**Retention:** The part of the gross storm rainfall which is intercepted, stored, or delayed, and thus fails to reach the concentration point by either surface or subsurface routes during the time period under consideration.

**Return Flow:** that part of irrigation water that is not consumed by evapotranspiration and that returns to its source or another body of water. The term is also applied to the water that is discharged from industrial plants. Also called Return Water.

**Return Seepage:** water which percolates from canals and irrigated areas to underlying strata, raising the groundwater level, and which eventually returns to natural channels.

**River Basin:** the total area (also called a watershed) drained by a river system. The river basin is regarded as a social and economic unit for community development and conservation of water, soil, forests and related resources. This concept recognizes the interrelationships of resource elements in a single basin, and assumes that multiple–purpose development can take these interrelationships into account. It exceeds the principle of ecological balance to the whole of the area and its occupants.

**River Stage:** is the elevation of the water surface at a specified station above some arbitrary zero datum.

**Routing:** a process of computing an unknown flow hydrograph at the lower end of a storage reach from a known hydrograph at the upper end of the reach. The routing interval is the basic time interval involved in a sequential routing (i.e., a weekly routing interval indicates that the routing will be composed of sequential periods one week in length).

**Salinity:** the relative concentration of salts, usually sodium chloride, in a given water. It is usually expressed in terms of the number of mg/1 of chloride.

**Saltwater Intrusion:** the phenomenon occurring when a body of saltwater, because of its greater density, invades a body of freshwater. It can occur in surface or groundwater bodies.

**Secchi Disc:** a circular metal plate, twenty cm in diameter, the upper surface of which is divided into four equal quadrants and so painted that two quadrants directly opposite each other are black and the intervening ones white.

**Secondary Treatment:** processes used to convert dissolved and colloidal materials in wastewater to a form that may be separated from the water. Commonly consists of biodegradation and conversion to cell mass in a separatable form with partial oxidation, such as in activated sludge, trickling filtration, or oxidation ponds.

**Sediment:** fragmental material, both mineral and organic, that is in suspension or is being transported by the water mass or has been deposited on the bottom of the aquatic environment. Sedimentation is the process of subsidence and deposition of suspended matter carried by water, sewage, or other liquids, by gravity. it is usually accomplished by reducing the velocity of the liquid below the point where it can transport the suspended material. Also called clarification, settling.

**Sediment Load:** the rate at which sediment passes a particular point on a stream for a given flow measured in dry weight as volume transported in a given time. Usually given in tons per day. This term may refer to a particular type of load; e.g. total, suspended, wash, bed, or bed material.

**Sediment Transport Routing:** the computation of sediment movement for a selected length of stream (reach) for a period of time with varying flows. Most sediment transport functions compute the bed material load capacity. The actual transport may be less than the computed capacity due to armoring, geologic controls etc. Application of sediment continuity relations allow the computation of aggradation and deposition as functions of time.

**Seepage:** 1. The slow movement of water through small cracks, pores interstices, etc., of a material into or out of a body of surface or subsurface water. 2. The loss of water by infiltration from a canal, reservoir, or other body of water, or from a field. It is generally expressed as flow volume per unit time. During the process of priming, such loss is termed absorption loss.

**Sheet Erosion:** the type of erosion which occurs when water flows in a sheet down a sloping surface and removes material from the surface in a sheet of relatively uniform thickness.

**Skimming:** the diversion of water from a stream or conduit by a shallow overflow used to avoid diversion of sand, silt, or other debris carried as bottom load.

**Sludge:** accumulated or concentrated solids from sedimentation or clarification of wastewater. Contains varying proportions of solids in wastewater depending upon source, process, and nature. Sludge banks are an accumulation of solids including silt, mineral, organic, and cell mass particulate material, that is produced in the aquatic system characterized by low current velocity, generally refers to gross deposits of appreciable depth. Sludge cake is the solid material remaining after dewatering sludge by vacuum, filtration, or sludge drying beds. Usually forkable or spadable, with a water content of thirty percent to eighty percent. May also occur on the surface waters.

**Solids, Dissolved:** solids which are present in solution.

**Solids, Settleable:** suspended solids which will subside in quiescent water, sewage, or other liquid in a reasonable period. Such period is commonly, though arbitrarily, taken as two hours. Also called Settling Solids.

**Solids, Suspended:** solids which are suspended in water which are either settleable or colloid and differentiated between dissolved solids.

**Solids, Total:** The solids in water, sewage, or other liquids; including the suspended solids (largely removable by filter paper), and the dissolved solids (those which pass filter paper).

**Solids, Volatile:** Organic fraction of the total solids.

**Sorption:** To take up and hold by either adhesion or incorporation. A collective term for absorption and adsorption.

**Storage Rule Curve Elevations:** In multiple–purpose reservoirs, it is common practice to establish elevation guidelines to govern the accumulation and drawdown of storage for various uses, with appropriate variations by seasons to conform with functional needs and run–off probabilities. For example, a "rule curve" or "guideline" may permit a relatively high reservoir level to be maintained for the benefit of hydroelectric power development during seasons of the year when flood problems are a minimum, and require drawdown to lower levels to provide greater storage space for flood control as the most severe flood season approaches. When it is necessary to store water above the "power pool rule curve" in order to control floods, such storage would normally be evacuated as promptly as possible without adding to downstream flood conditions, making releases not only through the power turbines but also through flood control outlets if necessary; in some cases, evacuation of storage above the power rule curve may be delayed to avoid or reduce wasting of water, if flood forecasts or probability analyses warrant such action.

Elevation rule curves are also used to govern seasonal changes in recreation pool levels, storage accumulation and drawdown for water supply, low–flow augmentation, and other multiple–purpose reservoir storage uses. These rule curves, established on the basis of economic studies and hypothetical reservoir operation and analyses usually have an important bearing on project design requirements.

**Stream:** A term for a body of flowing water. In hydrology, the term is generally applied to the water flowing in a natural channel as distinct from a canal, but is sometimes applied to a body of water flowing in a well–defined, open or closed conduit, a jet of water issuing from any opening, such as a nozzle, a fissure in rock, etc. More generally as in the term stream gaging, it is applied to the water flowing in any channel, natural or artificial.

**Streams in natural channels may be classified as follows:** (1). Relation to time (a) Perennial – one which flows continuously, (b) Intermittent or Seasonal – One which flows only a certain time of the year when it receives water from springs or from some surface source such as melting snow, (c) Ephemeral – One that flows only in direct response to precipitation, and whose channel is at all times above the water table. (2) Relation to space (a) Continuous – one that does not have interruptions in space, (b) Interrupted – one which contains alternating reaches, that are either perennial, intermittent, or ephemeral. (3) Relation to groundwater (a) Gaining – A stream or reach of a stream that receives water from the zone of saturation, (b) Losing – A stream or reach of a stream that contributes water to the zone of saturation, (c) Insulated – A stream or reach of a stream that neither contributes water to the zone of saturation nor receives water from it. It is separated from the zones of saturation by an impermeable bed. (d) Perched – A perched stream is either a losing stream or an insulated stream that is separated from the underlying ground water by a zone of aeration.

**Streamflow:** The discharge that occurs in a natural channel. Although the term discharge can be applied to the flow of a canal, the word streamflow uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than run–off, as streamflow may be applied to discharge whether or not it is affected by diversion or regulation.

**Streamflow Routing:** The technique used in hydrology to compute the effect of channel storage on the shape and movement of a flood wave.

**Subsurface Flow:** Water which infiltrates the soil surface and moves laterally through the upper soil layers until it enters a channel. Sometimes called Subsurface Run–off, Storm Seepage.

**Subsurface Water:** All water that exists in the interstices of porous earth materials, including soil moisture, intermediate zone water, capillary fringe water, and groundwater.

**Surface Run–off:** That part of the run–off which travels over the solid surface to the nearest stream channel. It is also defined as that part of the run–off of a drainage basin that has not passed beneath the surface since precipitation. The term is misused when applied in the sense of direct run–off.

**Suspended Bed Material Load:** That portion of the suspended load that is composed of particle sizes found in the bed material.

**Suspended Load:** The rate at which sediment in suspension passes a given point on the stream. Includes both suspended bed material load and wash load. Sediment that moves in suspension is continuously supported in the water column by fluid turbulence. Contrast with "bed load."

**Suspended Sediment:** The very fine soil particles which remain in suspension in water for a very considerable period of time without contact with the bottom.

**Suspended Solids:** The concentration of insoluble materials suspended or dispersed in waste or used water. Generally expressed in mg/liter on a dry weight basis. Usually determined by filtration methods.

**Tailrace:** A channel that conducts water from a forebay of a dam; afterbay.

**Thermal Stratification (of a lake):** Vertical temperature stratification that shows the following: The upper layer of the lake, known as the epilimnion, in which the water temperature is virtually uniform; a stratum next below, known as the metalimnion, in which there is a marked drop in temperature per unit of depth; and the lowermost region or stratum, known as the hypolimnion, in which the temperature from its upper limit to the bottom is nearly uniform. (See Overturn)

**Total Sediment Load:** The total rate at which sediment passes a given point on a stream (tons/day). Includes bed load, suspended bed material load, and wash load. In general, total sediment load cannot be directly measured and is difficult to calculate.

**Total Solids:** Refers to the solids contained in dissolved and suspended form in water. Commonly determined on a weight basis by evaporation to dryness.

**Toxic:** Chemical compounds or ions that are harmful to aquatic life.

**Turbidity:** Defined as capacity of materials suspended in water to scatter light. Measured in arbitrary Jackson Turbidity Units (JTU). Highly turbid water is often called "muddy" although all manner of suspended particles contribute to turbidity.

**Wash Load:** That part of the suspended load that is finer than the bed material and in near permanent suspension. Wash load is limited by supply rather than hydraulics. What grain sizes constitute was load varies with flow and location in a stream. Sampling procedures that measure suspended load will include both wash load and suspended bed material load.

**Water Pollution:** Any impairment of the suitability of water for any of its beneficial uses, actual or potential, by man–caused changes in the quality of the water.

**Water Quality:** 1. That phase of hydrology that deals with the kinds and amounts of matter dissolved and suspended in natural water, the physical characteristics of the water, and the ecological relationships between aquatic organisms and their environment. 2. A term used to describe the chemical, physical, and biological characteristics of water in respect to its suitability for a particular purpose. The same water may be of good quality for one purpose or use, and bad for another, depending upon its characteristics and the requirements for the particular use.

**Water Quality Criteria:** "A scientific requirement on which a decision of judgement may be based concerning the suitability of water quality to support a designated use."

**Water Quality Standard:** "A plan that is established by governmental authority as a program for water pollution prevention and abatement."

**Zooplankton:** The animals of the plankton. Unattached microscopic animals having minimal capability for locomotion.

## ACRONYMS

**AF:** Acre–feet

**B.C.:** British Columbia

**BLM:** Bureau of Land Management

**BMP:** Best Management Practices

**BPA:** Bonneville Power Administration

**CEAA:** Canadian Entitlement Allocation Agreements

**CFS:** Cubic feet per Second

**COE:** Corps of Engineers

**COLTEMP:** Columbia River Temperature Model

**CROHMS:** Columbia River Operational Hydro-Met System

**CWA:** Clean Water Act

**CZMA:** Coastal Zone Management Act

**DDE:** Dichloro–Diphenyl–Ethane (Pesticide)

**DO:** Dissolved Oxygen

**EIS:** Environmental impact statement

**EPA:** Environmental Protection Agency

**ESA:** Endangered Species Act

**FAUNA:** Friends and Advocates of Urban Natural Areas

**FDR:** Franklin D. Roosevelt

**FONSI:** Finding of No Significant Impact

**FPE:** Fish passage efficiency

**GIS:** Geographic Information System

**HEC:** Hydrologic Engineering Center

**HYDROSIM:** Hydro System Simulation Model

**JTU:** Jackson turbidity units

**KAF:** Thousand of acre–feet

**MAF:** Million Acre–feet

**NEPA:** National Environmental Policy Act

**NMFS:** National Marine Fisheries Service

**NPDES:** National Pollutant Discharge Elimination System

**NPPC:** Northwest Power Planning Council

**NPS:** National Park Service (NPS)

**NTU:** Nephelometric turbidity unit(s)

**NW:** Northwest

**PNCA:** Pacific Northwest Coordination Agreement

**PUD:** Public Utility District

**RCRA:** Resource Conservation and Recovery Act

**ROSE:** Operation System Expert Group

**SDWA:** Safe Drinking Water Act

**SEIS:** Supplemental EIS

**SNAG:** SOR NEPA Action Group

**SOR:** System Operation Review

**SOS:** System Operating Strategy

**SPCC:** Spill Prevention Control and Countermeasure

**TDG:** Total Dissolved Gas

**TSS:** Total Suspended Sediments

**USFS:** U.S. Forest Service

**USFWS:** U.S. Fish and Wildlife Service

**USGS:** U.S. Geological Survey

**WSU:** Washington State University

## SELECTED CHEMISTRY SYMBOLS

**Aluminium:** Al

**Argon:** Ar

**Arsenic:** As

**Barium:** Ba

**Beryllium:** Be

**Cadmium:** Cd

**Cerium:** Ce

**Chromium:** Cr

**Copper:** Cu

**Iron:** Fe

**Lead:** Pb

**Mercury:** Hg

**Nickel:** Ni

**Selenium:** Se

**Siver:** Ag

**Zinc:** Zn

## CHAPTER 8

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# TECHNICAL EXHIBIT A

# WATER QUALITY PARAMETERS OF SIGNIFICANCE TO COLUMBIA RIVER SYSTEM OPERATION REVIEW

## A–1 DEFINITION AND BACKGROUND

### Water Temperature

The physical characteristics associated with water temperature have major effects on the distribution of water in reservoirs because of the variable density of different temperatures. The temperature of water within a reservoir depends upon the volume and temperature of the entering water, the volume and temperature of the already impounded water, the surface area, weather conditions, the shape of the bottom of the reservoir, the location of the outlets for water withdrawal, and the rate of withdrawal.

Reservoir regulation (i.e., how a reservoir is refilled) also plays a major role in how solar radiation and atmospheric temperature affect the thermal characteristics of each type of reservoir. The thermal characteristics of the large storage projects are very different from those of the run–of–river projects. The deep storage projects have water retention times of several months to more than a year, are thermally stratified, and have complex hydro–dynamic thermal mixing characteristics. The relatively shallow run–of–river reservoirs have short retention times of only a few days, and have more uniform water temperatures from the surface to the bottom.

### pH

As an index of the hydrogen ion concentration, pH is measured on a scale of 0 to 14. A value of 7 indicates a neutral conditions; values less than 7 indicate acid conditions; and values greater than 7 indicate alkaline conditions in a water. The presence of carbonates, hydroxides, and bicarbonates decreases the acidity of water, while the presence of free mineral acids and carbonic acids increases its acidity. Acid mine drainage and industrial wastes that have not been neutralized may significantly lower the pH of the water. A pH range from 6.5 to 8.3 pH units is acceptable in drinking water. For the protection of aquatic environment, and aesthetic and recreational use, the pH should be between 6.5 and 9 pH units. Water with pH value outside the indicated range increases corrosion, adversely affects industrial processes such as bleaching, brewing, and photography, and increases water treatment costs.

### Dissolved Gas

Dissolved gas supersaturation is caused when water passes over a dam's spillway. The spilling water carries trapped air deep into the waters of the plunge pool or "stilling basin" where increased hydrostatic pressure dissolves the air into the water. At depth, this dissolved gas is "supersaturated" in relation to conditions at the surface. In addition, when brought to the surface, the gas will either come out of solution and equilibrate with atmospheric conditions or form bubbles. If these bubbles form within the tissue of aquatic organisms, they might injure or kill the organism. Since the dams have slowed the velocity, lessened the turbulence, and shortened the free–flow sections of the river, the river is not able to equilibrate the excess dissolved air between the dams, and the supersaturation condition can persist for extended distances. This is especially true during periods of high flow and continuous spillage.

Gas supersaturation has probably existed in the Columbia River System, even before Bonneville Dam was built in 1938. It has been known to occur in unimpounded natural streams like the Salmon River in rapids, waterfalls, and at points where a cold stream having high saturation concentration warms to a higher temperature. It is, therefore, likely that gas supersaturation occurred at the confluence of the Snake and Columbia Rivers and at Celilo Falls. However, natural supersaturation values were probably much lower than those caused by the dams. Higher flows induce increased mixing between water going over the spillway and water going through the powerhouse, thereby reducing the overall saturation of the project outflows. Although dissolved gas saturation may dissipate to some degree between dams, saturation levels become successively higher if all projects were spilling.

The seriousness of the problem of dissolved gas supersaturation in the Columbia River surfaced in spring 1968 when the powerhouse for John Day was constructed. The project was closed during part of the construction and the entire flow of the river was passed over the spillway. Many adult salmon died of gas bubble disease that resulted from the spill.

Dissolved gas supersaturation associated with Corps dams in the Columbia–Snake River System has generally exceeded the maximum acceptable standard of 110 percent saturation. One problem is the release of water over the spillways, much of which is provided for fish passage. However, waters entering the impoundments from Canada and possibly from the upper Snake River are already supersaturated with dissolved gas.

The Corps has made major efforts to reduce gas supersaturation in the Columbia River System. One approach has been to develop structural components called "flip lips" that were installed in the mid–1970s at the base of some Corps' spillways (e.g., Bonneville and Lower Monumental dams). These flip lips were designed to reduce the plunge of water into the pools below the dams, and consequently, avoid the hydrostatic pressure that forces the atmospheric gases into solution. Neither spill control (e.g., reservoir regulation and releases through turbines to minimize spill) nor flip lips have been completely effective in reducing dissolved gas to safe levels.

Dissolved gas concentrations in the Columbia River System have been monitored by the Corps' North Pacific Division since 1968. A Dissolved Gas Monitoring Program became an integral part of the daily reservoir regulation activities during 1979. In 1984, the number of dissolved gas monitoring stations was increased from 5 to 15 sites. These sites range from the international boundary to downstream of Bonneville Dam (RM 145). The concentration of dissolved gas is measured at each major area of concern during the late spring and summer when significant spill is expected in the system. Spills from the dams are then adjusted by shifting the power loads to other dams in the system to minimize spill and gas supersaturation.

**Suspended Sediment**

Several nonpoint source activities cause accelerated sedimentation, which adversely affect aquatic habitat. The amount of fine sediment is especially important for the survival of salmonids. Fine sediment interferes with the flow of water through spawning gravel and therefore affects the transport of oxygen to the incubating eggs. High sedimentation rates can also fill deeper pools in streams which are important for overwintering of fish and cold water refuges in the summer.

Sediment is by volume the greatest single pollutant of surface waters and has been identified as a major problem in irrigation return flow and agricultural run–off in the Pacific Northwest (King et. al, 1978). In addition to the aesthetic problem of "muddy water", deposition of suspended sediments reduce the capacity of conveyance structures and systems and seriously decrease reservoir storage capacity. On–farm deposition can produce crusts that inhibit water infiltration and can contribute to salinity problem by hindering leaching of saline soils.

Suspended solids in the Columbia River rarely exceed 1,000 parts per million (ppm), and the annual suspended sediment load averages about 15,000,000 cubic yards for the entire river. Approximately 98 percent of dredged Columbia River bed sediments below Bonneville Dam is clean, fine sand. The remaining material is typically organic matter that might come from log rafts, wood debris, fish and waterfowl carcasses, aquatic vegetation, domestic and industrial waste discharges, agricultural run–off, and other miscellaneous materials. At present, these organic materials have little, if any, effect on water quality because they are usually diluted by the large flows of the Columbia River.

**Turbidity**

Turbidity is a measure of light scattered or absorbed by the suspended particles such as silt, clay, organic matter, plankton, and microscopic organisms in water which are usually held in suspension by turbulent flow and Brownian movement. These particles usually result from natural erosion, run–off, and algae blooms although man may also contribute to the presence of such materials. Non–detectable turbidity may be approximated by pure distilled water (0 Jackson turbidity units, JTU). Values of 1000 JTU may be encountered in wastewater; waters with very high natural turbidity may be in the range of several hundred JTU.

Another turbidity standard is expressed in NTU (nephelometric turbidity) unit. In this case, the intensity of light scattered by particles suspended within a sample is compared with the intensity of light scattered by a standard reference solution. The higher the scattering, the greater the turbidity.

High turbidity reduces photosynthesis of submerged aquatic vegetation and algae; this reduced plant growth may in turn suppress fish productivity. High turbidity also affects domestic, industrial, and recreational uses of a water.

Although suspended sediments are one of the main causes of turbidity, their interrelationship is a subject of considerable controversy. Turbidity and suspended sediment concentration measured for agricultural and irrigation return flows, for example, frequently show minimal correlation except at specific sites and for short–term events. Significant influencing factors include particle size, index of refraction, concentration and angle of scatter. Based on studies made in 1978 by the Washington State Water Research Center in selected agricultural areas in the Pacific Northwest, only particles of less than 10 microns in diameter have been found to contribute significantly to turbidity.

**Metals**

IRON. Industrial wastes, acid mine drainage, mineral processing, and the corrosion of iron and steel may contribute iron to the environment. In water, iron can discolor clothes, plumbing fixtures, and cause scaling which encrusts pipes. It is highly objectionable for drinking water because of its bittersweet astringent taste.

LEAD. Man's input of lead to the environment outweighs all natural sources. The burning of leaded fuel, particularly, automobile fuel, is one of the main culprits. Other sources include ore smelting and refining, production of storage batteries, lead pipes, and recycling lead products and motor oils. Lead derivatives are used in industries, printing and dyeing operations, photography, engraving, and manufacturing of explosives. The presence of lead limits the use of some waters as sources for public drinking supplies.

MERCURY. Mercury compounds are used in a number of commercial and industrial processes. Although discharge limits have been set for chlor–alkali plants, which produce chlorine gas and hydrochloric acid, mercury may still be discharged in their wastewaters. Some mercury is also associated with the manufacture of paints; electrical equipment such as mercury vapor lamps; dental amalgams; and some therapeutic medicinal compounds. Some pesticides used to have a mercury base. waters with high mercury concentrations are unsuitable for drinking sources and for certain agricultural uses. The bioaccumulation of mercury in the food web may render certain aquatic organisms, especially fish, unsuitable for human consumption.

**Toxic chemicals in water, sediment and fish tissues**

Toxics are sampled less frequently than conventional parameters due to the large number of potential compounds which could be analyzed and the generally greater expenses of the analyses. The major types of toxics of potential concern in the Columbia Basin are pesticides, dioxins and furans, PCBs, heavy metals, and radionuclides. The major sources are industrial and municipal discharges, agriculture, forestry, and stormwater run–off.

The above types of toxics have been identified at levels of concern in various parts of the Columbia River Basin. The greatest concentrations have generally been measured in either sediments or fish tissue. Although pesticides, dioxins and PCBs have been implicated in reduced reproductive success of eagles, it is not known whether existing levels in fish are affecting their populations. The significance of toxics accumulating in sediments is even less well understood. Little data exists on sediment concentrations in the highly depositional areas behind the dams.

**Organic carbon**

Organic carbon compounds may be formed by photosynthesis within the aquatic environment. Plant and animal materials contribute organic carbon to the aquatic environment. Run–off from agricultural lands and municipal and industrial waste discharges, especially from the pulp and paper industry, may further increase the levels of the total organic carbon in water.

Although carbon is a nutrient required for biological processes and a component of photoplasm, the decomposition of carbon compounds removes oxygen from a water. Excessive amounts of organic carbon can lower dissolved oxygen to levels below that required by aquatic organisms.

Volatile organic compounds

**Adsorbable organic halides**

Halides generally include bromide, chloride and fluoride. In most waters, chloride is a major constituent, and the other two are either minor or trace constituents.

Bromide may be weathered from soils or discharged from chemical industries. The weathering and leaching of soils release chloride to water. The disinfection of domestic sewerage and industrial processes that use chlorine may produce further residual chlorine concentrations, which are subsequently transformed to chloride. Household cleansers and the salting of roads in winter are two other common sources of chloride. Fluoride in this region comes from insecticides and herbicides washed off by agriculture run–off. Sewage effluents from municipalities using fluoridated drinking water may also discharge fluoride into waters.

**Nutrients**

Nutrients stimulate algal growth which increases BOD and thereby decreases minimum DO. Some streams in the Columbia River Basin have had problems with excess nutrients. Nutrients come from a number of sources including grazing, agriculture, and sewage treatment plant effluent.

**Bacteria of public health importance**

Areas of concern with human health relate primarily to human pathogens and bioaccumulation of toxics in the tissue of organisms eaten by man. Fecal coliform bacteria concentrations in some parts of the basin have occasionally exceeded water quality standards. Enterococcus bacteria, another indicator of human pathogens, was measured at 6 stations below Bonneville during the Bi–State reconnaissance survey; all stations exceeded water quality standards. As noted above, toxics have been measured at levels of concern in fish tissue. Human health risks associated with these contamination levels have not been thoroughly evaluated. Risks depend in part on consumption rates which are currently being studied for Native Americans,a group likely to be consuming significant amounts of Columbia River fish.

**Radionuclides**

Small amounts of radioactive wastes continue to be released from nuclear power plants and processing plants, and to a lesser extent, from laboratories and hospitals. Highly radioactive wastes, such as spent reactor fuel, are stored underwater in special tanks, whereas small volumes of low level radioactive wastes are diluted and dispersed directly into the aquatic environment, particularly in the ocean. The most common naturally occurring radionuclides are radium–226, radon–222, thorium–232, and to a lesser extent, uranium–238.

Radiation is harmful to humans, causing damages to both the cellular and molecular levels. Radionuclides in irrigation waters may be bioaccumulated by the crops and subsequently consumed by man. A level of contamination harmful to humans would be reached before any plant damage could be observed.

**Pesticides**

Pesticides are chemical compounds (organic or inorganic) used to control noxious "pests" that attack crops, animals, and man. They have both beneficial and detrimental characteristics. A major concern with pesticides is their accumulation in the environment and, in particular, their biological magnification in the food web. They may also be found in substantial amounts in the sediments.

Pesticides may reach the aquatic environment in a number of ways: (1) drift from aerial spray, (2) surface run–off, (3) percolation and subsurface run–off from treated lands, (4) careless application or spillage, (5) direct aquatic application to control undesirable aquatic organisms, and (6) sewerage discharge and industrial effluents.

**Groundwater**

Three major relevant interactions between groundwater and surface water are (1) the cooling effects of groundwater inflows on surface waters; (2) effects on stream banks from changes in groundwater levels; and (3) contamination of surface water from groundwater sources. Limited information is available on these interactions at this time for most areas of the Basin.

**Water Quantity**

In addition to water chemistry and habitat problems in the Columbia caused by the introduction of contaminants or by habitat modifications, the alteration of natural river flow associated with dams, power generation needs, drawdown programs, irrigation, or other consumptive use can exacerbate existing water quality problems. Quantitative data characterizing the interaction of water quantity and water quality in the Columbia Basin is, however, generally scarce.

High flow years are characterized by heavy sediment transport and high turbidity as a result of wetter soils that can be eroded more easily, and greater current velocity that accelerate the soil erosion process. More pollutants are also washed off from watersheds because of the higher run–off, with greater sediment carrying capacity. Dilution ratios increase as a result of high flows; streams have a greater assimilative capacity.

During low flow years, especially during drought conditions, water quality can be affected in an even greater number of ways. Concentrations of salt can build up as normal flushing is disrupted by low streamflows. Bacterial counts as water temperature rises. Increased blue–green algae blooms mark significant changes in water conditions, which can be measured in the pH and dissolved oxygen levels of streams, lakes, and reservoirs.

Drought was found to have caused both deterioration and improvements in some water quality indicators (National Study of Water Management During Drought, Corps of Engineers, August 1991). Negative impacts include an increase in ammonia and manganese concentrations and, to a lesser degree, increased phenol and specific conductance. Drought–induced water shortage also reduces the flushing capability for effluent discharges, since there is not enough water to dilute the discharge. On the positive side, concentrations of nitrite and nitrates, total iron, and the number of coliform bacteria can decrease significantly due to the drought.

Finally, low streamflows increase the extent of annual intrusion of salt water from the ocean in the estuary area. Because the volume of water flowing into the ocean is reduced, the intrusion of salt water may begin earlier than normal.

## TECHNICAL EXHIBIT B

## HISTORICAL AND CURRENT WATER QUALITY CONDITIONS

### B–1 INTRODUCTION

As part of the Task One technical support services provided to the U.S. Army Corps of Engineers (the Corps), Walla District, Ebasco has gathered, reviewed and analyzed existing water quality data for the Columbia River System Operation Review (SOR). The SOR project is a multi–agency study led jointly by the Corps, the Bonneville Power Administration (BPA), and the Bureau of Reclamation (the Bureau). The Corps is a key participant on the SOR Water Quality Work Group, which has developed plans and methods for conducting full–scale analyses of the alternatives to be evaluated for the SOR. This report is a general overview of key conventional water quality parameters, but does not include any analysis for evaluation purposes. Basic characterizations of historical and current water quality conditions in the Columbia River Basin are included, and changes in water quality over time are indicated.

The water quality parameters selected for this task are significant for aquatic ecology and its relationship with beneficial uses of water resources. These parameters include:

- temperature
- dissolved oxygen
- pH
- suspended sediments
- turbidity
- nitrogen and phosphorous.

Many agencies and investigators have produced analytical data on this list of parameters. Data from the period 1974–1993 have been retrieved for this report. The data represent concentrations measured in samples taken within the geographic area covering the entire mainstem of the Columbia River and its major tributaries within the United States. The tributaries include the Yakima, Snake, Clearwater, Spokane, Pend Oreille, Flathead and Kootenai Rivers. The Corps, U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), and the Washington State Department of Ecology (WDOE) maintain water quality databases storing data from samples taken during this time period and in this area. This report characterizes this data set and other data summaries contained in significant earlier literature on Columbia River water quality.

### B–2 METHODS

Characterization of water quality included a search of existing data sources, data retrieval and organization into a specific format, a sort of the data by sample location and time, a trend analysis, a sampling frequency analysis and long–term data gap identification, and computation of mean and extreme concentrations. This report characterized Columbia River water quality information found in databases maintained by the Corps, EPA, USGS and WDOE. Additional information was obtained from literature provided by members of the SOR Water Quality Work Group and other literature sources.

### B–2.1 DATA SOURCES

Columbia River water quality databases contain data from many sampling and analysis programs. The Corps database consists of samples collected by the Corps in McNary Pool (Lake Wallula) on the Columbia River, and in the Ice Harbor, Lower Monumental, Little Goose and Lower Granite Pools on the Snake. USGS water resources data from tile western U.S. are contained in the EARTHINFO water quality database. All WDOE data are archived in their Ambient Monitoring Program database. The EPA STORET database contains some duplication of the USGS data, and provides additional summary information. A description of the procedure used to characterize data from each of these sources follows.

### B–2.1.1 Corps Database

The Corps information consists of data from their own sampling activities only. Their database was provided by the Walla Walla District in electronic spreadsheet format. Composite and depth profile samples were taken and summarized separately. Samples from all locations were analyzed for temperature, dissolved oxygen (DO), DO saturation, turbidity, carbon dioxide ($CO_2$), pH, conductivity, hardness (total, calcium, and magnesium), biological oxygen demand (BOD), total and ortho–phosphate, and nitrates. The number of sampling days for each parameter at each location were counted, and the observed concentration ranges were determined. Gaps in sampling spanned one or more years, so the years in which sampling occurred were also identified. Because of the importance of reservoir bank erosion expected during the proposed drawdown operations at the Snake River dams, the relationship between sedimentation/turbidity and discharge was displayed. Secchi disk measurements were taken by the Corps in the fish ladders at Ice Harbor, Lower Monumental, and Little Goose dams on the Snake. This measure of water transparency was used to indicate turbidity. For the period 1985–1991, daily secchi disk data were plotted with discharge to show this relationship.

### B–2.1.2 USGS Database

The USGS conducts long–term water quality sampling within the basin at the locations listed in Table B–1. In general, a few samples are taken seasonally, and analyzed for conventional water quality parameters and others such as metals. Their data are retrieved and reformatted into a privately maintained database by Earthinfo Inc. (EARTHINFO). The EARTHINFO database includes USGS data only. The Corps Walla Walla District provided the EARTHINFO database for this study. Parameters in addition to those included in the Corps database were retrieved from the EARTHINFO database. They are: turbidity, conductivity, total alkalinity, total and dissolved nitrogen, ammonia and ammonium nitrogen, nitrite and nitrate nitrogen, total sulfate, dissolved salt ions (calcium, sodium and potassium), total chloride, and suspended sediments. Mean annual concentrations for each parameter, at each location, for each year sampled were calculated. The minimum and maximum concentrations for the entire period of record at each location were reported with mean annual concentrations.

### B–2.1.3 WDOE Database

The WDOE Ambient Monitoring Program analyzes grab samples from three main stem reach locations on a regular basis, and up to four other locations non–continuously. Tributaries including the Yakima, Spokane, and Pend Oreille rivers are also monitored. In general, the samples were analyzed for conventional water quality parameters. Samples from some locations were additionally analyzed for chemical oxygen demand (COD), fecal coliforms (FC), nutrients, and metals. These data were compared to the USGS data to determine if WDOE concentrations were outside the minimum and maximum range of concentrations retrieved from the EARTHINFO database.

### B–2.1.4 EPA Database

The EPA maintains a national water quality database called STORET in which any agency's or private investigator's data can be archived. Most USGS data included in the EARTHINFO database should be in STORET. STORET does include the long–term USGS water quality sampling locations along the mainstem Columbia and Snake. Additionally, STORET includes a large number of infrequently sampled locations along the mainstems and tributaries. The reported concentrations from these infrequently sampled locations were compared to the minimum and maximum USGS sample concentrations, period of record, and number of samples retrieved from the EARTHINFO database.

## B–2.2 TEMPORAL AND SPATIAL DISTRIBUTION OF DATA

One of the greatest concerns of any water quality study is the adequacy of the available data to meet the needs of the study objective. A main SOR project objective is to predict how system operation changes will affect existing water quality. Knowledge of existing water quality should be based on results from laboratory analysis of samples collected throughout the system over time. The points and times of field sampling and laboratory analysis were investigated to show what hard evidence of the system's water quality actually exists. The adequacy of these data for use in predictive methods greatly depends on the results of this analysis. Both methods for determining the frequency of sampling and parameter analysis of the samples are described here.

### B–2.2.1 Sampling Frequency

All sampling locations included in the four databases were analyzed for period of record and sampling frequency for the purpose of selecting locations for evaluation of longterm water quality trends. The number of years in which sampling occurred were counted for each location. Where database summaries were available, the number of samples collected were counted for each sampling location. The locations where the most agencies sampled for the longest periods were selected for long–term trend analysis. Generally, sampling period of records greater than 12 years within 1975 to 1993 were considered long–term and frequently sampled locations. This period of record was used to select locations for evaluation of water quality changes over time.

All mainstem Columbia and Snake locations, in addition to the major tributary locations, needed to be represented in the trend analysis. Some tributaries and Snake River locations had a period of record less than the 12 year selection criterion, but were included because they were the most frequently sampled location within a relatively infrequently sampled tributary, or because of their importance to this study.

### B–2.2.2 Parameter Analysis Frequency

The frequency of sampling at a site does not necessarily equal a parameter's analysis frequency at that site. In other words, each sample may only be analyzed for a few, and not all, parameters. In order to compare the frequency of analysis of the parameters at each site, a rating factor for each parameter–site pair was computed. First, the number of years a site was sampled was counted. This was the site period of record. Next the number of years in which the samples were analyzed for a parameter was counted. The total number of parameter analyses made during those years was also counted. The rating factor equalled the number of analyses per site period of record, times the ratio of years analyzed to the study period (20 years). This rating factor indicated the average number of times a parameter was analyzed in a year at a specific site over the course of the study period (1974 to 1993).

### B–2.2.3 WATER QUALITY PARAMETER RANGES

The minimum and maximum values reported in each of the four databases for all the parameters analyzed from samples taken at each long–term sampling location during the study period were tabulated for easy comparison. The extreme values of all the databases for all parameters were grouped by sampling location. The locations were grouped by river: the Columbia, Snake and Clearwater, and other major Columbia tributaries upstream of the Snake confluence. Three graphs were made for each parameter. The locations placed on the graphs horizontal axes are from left to right in progressively upstream order. So the location nearest the mouth is farthest to the left side of the graph, and the upstream most location is on the right side.

While performing the parameter range analysis, a comparison of data duplication between databases was made to show if the collection agencies were exchanging data. This evaluation also resulted in a data sharing evaluation byproduct. The EPA STORET database is the official national water quality database, but not all water quality monitoring programs submitted their analytical results to the EPA for archiving.

## B–2.3 TREND ANALYSIS

Historical trends in water quality dating back to before the mid–1970's, and from 1974 to present, were determined by comparing the data summarized from the Corps, USGS, EPA and WDOE databases with pre–1974 data found in the literature. The Stober and Nakatani (1992) report on Columbia River System water quality includes data from 1954 to 1984. The data from the most current samples included in the above databases were used to represent current conditions in this trend analysis. The concentrations were plotted versus time to show if significant changes had occurred. An additional analysis was made to determine the correlation of secchi disk measurements taken in Lower Snake River fish ladders with dam discharges.

## B–3 RESULTS

The water quality variables specifically addressed included temperature, pH, conductivity, hardness, dissolved oxygen, turbidity, and nutrients. Nutrient parameters include total nitrite and nitrate nitrogen ($NO_2+NO_3$), ammonia and ammonium nitrogen ($NH_3+NH_4$), total phosphate (TP), and dissolved ortho–phosphate (OP). These parameters were selected because they are significant to anadromous and resident fish, and to reservoir eutrophication. The full–scale analysis plan for the SOR water quality study focused on these conventional and nutrient water quality parameters. The plan indicated the need to summarize data on these parameters for system model validation, on a monitoring site basis. The water quality databases from the four agencies were summarized and compared with each other using only the monitoring sites with relatively long–term records. The screening process for determining long–term sampling locations, and the ranges of all water quality parameter concentrations (except hardness for EPA data) are described below.

### B–3.1 SAMPLING AND PARAMETER ANALYSIS FREQUENCY

The sampling frequency analysis screened out sampling locations that were not sampled on a regular basis. Only by comparing data from long–term sampling locations can water quality changes over time be ascertained. The long–term sampling locations referred to in this overview of Columbia River water quality are identified in Figure B–1.
A description of the period of record, sampling gaps, and parameters analyzed for each river's monitoring locations follows.

#### B–3.1.1 Columbia River

Eight long–term water quality monitoring sites are located on the Columbia River:

- Warrendale, OR
- Umatilla, OR
- McNary, WA
- Above Snake Confluence at Richland, WA
- Vernita, WA
- Rock Island, WA
- Grand Coulee, WA
- Northport, WA

Warrendale is a monitoring site just downstream of Bonneville Dam. The USGS started sampling there in 1988. The WDOE sampled there between 1975 and 1979. The USGS analyzed all parameters except hardness, $NO_2+NO_3$, $NH_3+NH_4$, and OP. The WDOE analyzed all parameters except conductivity, DO, $NO_2+NO_3$, and OP. Neither the Corps nor EPA sample here. Temperature and OP were the most frequently reported parameter, included in 62 samples by WDOE over a five year period.

Umatilla is currently an EPA and WDOE site. Sampling occurred from 1975 to 1980, then the next ten years were skipped. Sampling resumed in 1990. EPA analyzed all parameters except suspended sediments and turbidity. WDOE analyzed all parameters. Neither the Corps nor the USGS sample here. Temperature was the most frequently reported parameter, at 79 samples by WDOE over a nine year period.

McNary Pool at river mile 295 is currently a Corps sample site, and the EPA sainpled here from 1974 to 1976. The Corps analyzed all parameters except for suspended sediment and $NH_3+NH_4$. EPA only monitored temperature and DO three times. Corps monitoring was not continual, and DO was the most frequently reported parameter, at 37 samples over the 18 year period.

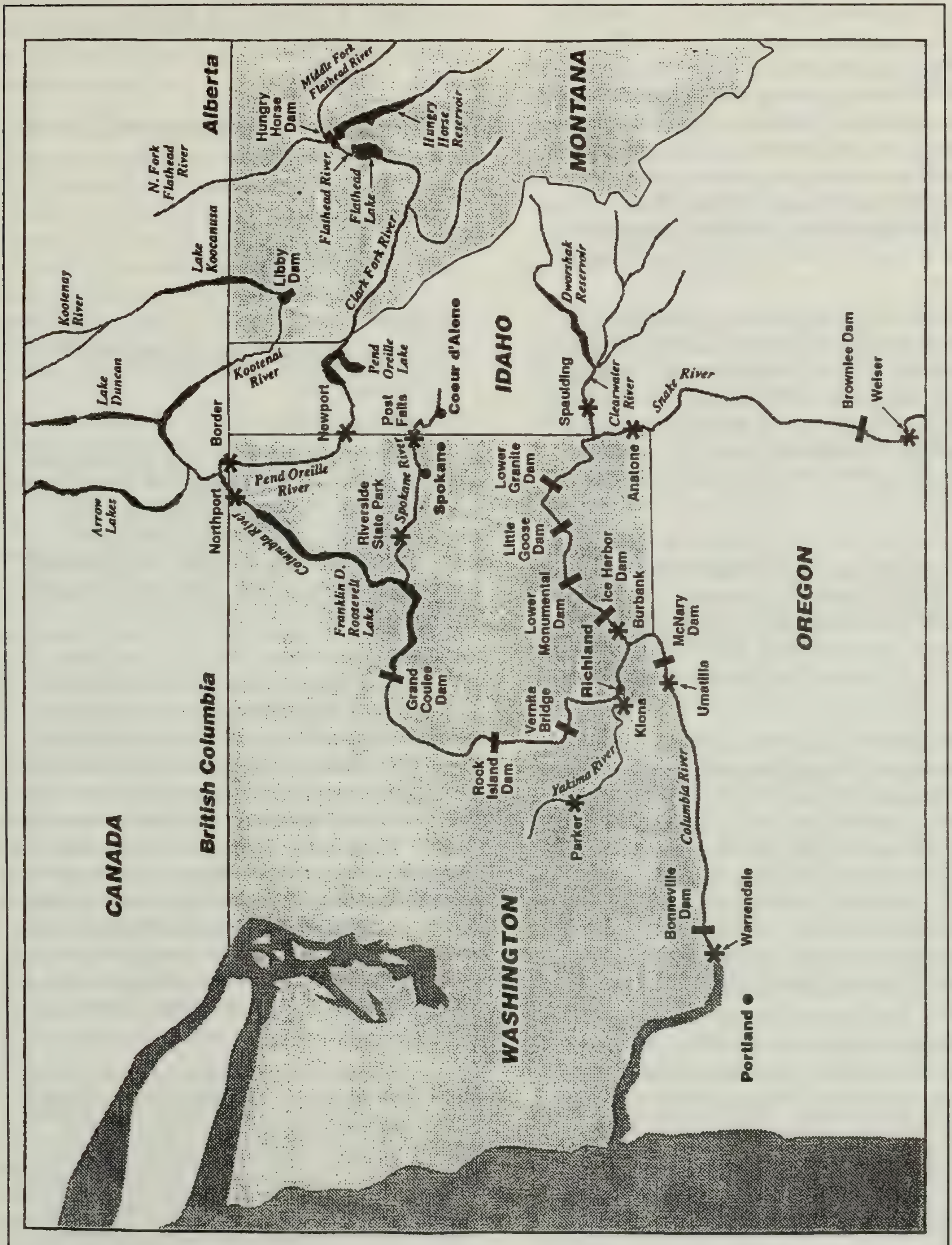

Figure B–1. Long-Term Water Quality Sampling Sites instream (*), and at Bureau of Reclamation and Corps of Engineers dams.

Richland is upstream of the Snake River confluence. This site is sampled extensively by the USGS and EPA. The Corps and WDOE do not sample here. The USGS started sampling here in 1979 and continued through 1990. EPA sampled throughout the entire study period. Temperature, DO and conductivity were sampled on average about nine times a year by EPA. Turbidity, pH, TP and OP averaged five to six samples a year. The USGS sampled an average of once per year for all parameters except nutrients.

Vernita sampling is long–term and frequent. The USGS, EPA and WDOE report samples throughout the entire study period. WDOE stopped sampling in 1990, but USGS and EPA continued. An average of 9 to 10 samples per year are reported by the three agencies for all parameters except for nitrogen. $NO_2+NO_3$ and $NH_3+NH_4$ are sampled half as often.

Rock Island is a long–term WDOE monitoring site. WDOE reports sampling throughout the entire study period. USGS reports samples between 1975 and 1980. EPA reports samples from 1976 to 1977. The Corps does not sample here. WDOE samples on the average of 10 per year. All parameters are analyzed as frequently, except $NO_2+NO_3$ and hardness.

Grand Coulee is a long–term EPA and WDOE monitoring site. The USGS reports sampling about once a year from 1975 to 1980. Most of the ranges in parameter concentrations are the same for the EPA and WDOE reports. This indicates that the WDOE is sending its data to EPA, who is archiving it in STORET. Sediment is the exception. EPA reports no sediment analysis for any samples. WDOE samples on the average of 10 per year. All parameters are analyzed as frequently, except $NO_2+NO_3$ and hardness.

Northport is a long–term USGS and EPA monitoring site. Both agencies report sampling throughout the entire study period. WDOE reports sampling from 1975 to 1981. Many of the parameter concentrations are the same in all the agency reports, again indicating that agencies are exchanging data. The frequency of parameter analysis varies. Temperature and conductivity are analyzed most frequently, at an average of 10 per year, followed by DO, TP and sediment, at an average of nine, seven, and five per year, respectively.

### B–3.1.2 Snake River

Eight long–term water quality monitoring sites are located on the Snake River:

- Burbank, WA
- Ice Harbor, WA
- Lower Monumental, WA
- Little Goose, WA
- Lower Granite, WA
- Lower Granite at river mile 120, WA
- Anatone, WA
- Weiser, ID

Burbank is a USGS site. They have reported sampling throughout the study period. No other agencies sample here. The average sampling and analysis frequency for all parameters except nitrogens, hardness and OP is once per year. The parameters with a less frequent analysis still average at least once every 2 years.

Ice Harbor Pool at river mile 18 is a long–term Corps monitoring site. EPA reported sampling in 1975 only, and the USGS does not sample here. WDOE reports sampling from 1975 to 1990. The Corps do not sample as frequently as WDOE. The Corps analyzed for temperature, conductivity, DO, pH and turbidity on the average about 3 times per year for 9 years out of their 18–year period of record. WDOE analyzed temperature, conductivity, pH, sediment and turbidity on the average of about 10 times a year. STORET reports intensive water quality sampling in 1975 on the Snake River starting at Ice Harbor. Up to 19 samples are reported for 1975 alone, with sampling upstream at regular intervals.

Lower Monumental Pool at river mile 44 is a long–term Corps monitoring site. EPA reported sampling in 1975, with only five samples taken that year. WDOE and the USGS do not sample here. The Corps reports sampling from 1978 to 1992, with an average frequency of 3 per year for temperature, conductivity, DO and pH. The Corps had sampled only 14 years out of their 18–year period of record.

No sediment data are reported, but turbidity data are reported at a slightly higher frequency than temperature. Nutrients and hardness have only been analyzed a few times.

Little Goose Pool at river mile 83 is a long–term Corps monitoring site. EPA reported sampling in 1975, with only five samples taken that year. WDOE and the USGS do not sample here. The Corps reports sampling from 1978 to 1992, with an average frequency of one per year for temperature, conductivity, DO, pH and turbidity. The Corps had sampled only nine years out of their 18–year period of record. No sediment data are reported. Nutrients and hardness have only been analyzed a few times.

Lower Granite Dam at river mile 107 is a long–term Corps monitoring site. Corps sampling is reported for 9 years during the 1978 to 1989 period of record. Conventional parameter analyses are reported on the average about twice a year. The USGS reports sampling once per year from 1975 to 1978. EPA reports sampling up to 25 times per year from 1975 to 1977. WDOE does not sample here. No sediment analysis is reported for any sample taken here.

Lower Granite at river mile 120 is a long–term Corps monitoring site. The period of record for Corps sampling is from 1978 to 1992. However samples had only been taken for 9 years within this period of record. The USGS reports sampling for 4 years prior to the Corps sampling. The USGS sampling frequency averages about one per year. The Corps sampling frequency averages two per year for those years when they sampled. The Corps reports conventional parameter results for most samples, but there are half as many nutrients analysis reports. There are no reported sediment and ammonia concentrations from the Corps. The USGS reports results for all parameters except sediment, TP and OP.

Anatone is a long–term USGS monitoring site. No other agencies report sampling here. The USGS reports sampling throughout the entire study period, but only temperature and conductivity are reported regularly, at an average of once per year. There are no OP analyses, and the other parameters are reported an average of once every two to three years.

Weiser, Idaho is a long–term USGS monitoring site. No other agencies report sampling here. The USGS reports sampling throughout the entire study period. Temperature, conductivity, DO, pH, turbidity, and TP results are reported regularly at two to three per year. The USGS reports results for the other parameters at least once every two years, except for OP.

### B–3.1.3 Clearwater River

Only the USGS reports long–term water quality monitoring on the Clearwater River. Sampling at Spaulding, Idaho is reported throughout the entire study period. Temperature and conductivity are reported most frequently at once per year, followed by sediment, turbidity, TP, DO and pH at a slightly lower frequency. Hardness is not reported at all, and the remaining parameters are reported at most once every 2 years.

### B–3.1.4 Yakima River

Two long–term water quality monitoring sites are on the Yakima River in Washington:

- Kiona
- Parker

Kiona is sampled by the USGS and WDOE. The USGS reports sampling throughout the entire study period, and WDOE reports sampling from 1975 to 1986. The USGS sampling frequency here averages about one per year, whereas the WDOE averages 10 per year. The USGS reports regularly on all the parameters, except for $NO_2+NO_3$ which is reported about once every other year. The USGS does not analyze for hardness here at all. WDOE regularly report temperature, conductivity, pH, and turbidity. Sediment and hardness are reported seven to eight times per year by WDOE. WDOE does not report DO or nutrient sampling here.

Parker is a long–term WDOE monitoring site, but no sampling is reported after 1986. No other agencies report sampling here, the total WDOE period of record within the study period is 12 years. Temperature, conductivity, DO and turbidity are reported regularly at 12 to 13 per year. Ten years of sediment sampling are reported, with a frequency of about 10 per year. Hardness is reported 18 times, but for one year only. DO and nutrients sampling are not reported here.

#### B–3.1.5 Spokane River

Two long–term water quality monitoring sites are on the Spokane River:

- Riverside State Park, WA
- Post Falls, WA

The combined sampling period of record of the two monitoring sites span the entire study period. WDOE is the only agency reporting sampling at these two sites. Sampling reports during the study period for Post Falls start in 1975 and end in 1986. Riverside reports start in 1986 and continue to the present. Ten samples per year are reported at both sites. Temperature, conductivity, pH, sediment, and turbidity are reported regularly. Hardness is reported nine times per year. No DO or nutrients samples are reported here.

#### B–3.1.6 Pend Oreille River

There is one long–term water quality monitoring station on the Pend Oreille River at Newport, WA. One other site is included here because of its important location at the international boundary. Both sites are sampled by WDOE. No other agency samples here. The period of record at the Border site started in 1975 and ended in 1981. Recorded sampling at Newport during the study period starts in 1975 and ends in 1986. Temperature, conductivity, pH and turbidity are reported regularly at both sites. The reported sampling frequency is about 10 per year for these parameters. Hardness is also reported at this frequency for the Border site, but only half as often at Newport. Sediment sampling is reported for only a portion of the years within both sites' periods of record, but at 8 to 10 samples per year for the years sampled. No DO or nutrient sampling is reported here.

#### B–3.1.7 Flathead River

The USGS is the only agency of the four that monitors water quality on the Flathead River. They have sampled near Columbia Falls for nearly the entire study period. USGS sampling records for near Columbia Falls end in 1989. None of the parameters reported show a regular sampling frequency. Temperature and conductivity are reported most often at 11 years out of the 14 year period of record. The other parameters except for OP are reported for 4 years or less. No OP analyses are reported here.

#### B–3.1.8 Kootenai River

The USGS is the only agency of the four that monitors water quality on the Kootenai River. They have sampled at Libby Dam (river mile 221) for the entire study period. Temperature, conductivity, DO, pH and TP have been analyzed yearly. $NO_2+NO_3$ is reported for 15 years. $NH_3+NH_4$, OP and hardness analyses are reported on the average every other year. Turbidity is reported for only a couple of years. Sediment is not reported here by the USGS.

### B–3.2 PARAMETER ANALYSIS FREQUENCY SUMMARY

The frequency of long–term monitoring site sampling and analysis of the water quality parameters included in this study is summarized in Table B–1. The columns are parameters and the rows are sites. The sampling frequency for all the parameter–site pairs are lumped into four categories: high, medium, low and none (not sampled, nor analyzed). The rating factor ranges for each category are:

| | |
|---|---|
| high | 6.0 and greater |
| medium | greater than or equal to 4.0 |
| low | less than 4.0 |
| none | 0 |

In general, high rating factors represent a sampling frequency that is at least once a month during growing season, medium is at least once a season, and low is less than once a season, but not zero.

## B–4 PARAMETER RANGES

The number of observations of each parameter reported in the EPA STORET database from 1974 through 1992, and the mean, standard deviation, maximum and minimum of the detected values at all sampling locations on the mainstem Columbia River downstream of the international boundary, and on the mainstem Snake River downstream of Washington–Idaho state boundary are listed in Table B–2. Table B–3 contains extreme parameter values reported in the four databases for each of the long–term sampling locations. Following these tables are graphs of the highest maximum and lowest minimum reported values in all the databases for each parameter.

## B–5 HISTORIC TRENDS

Data collected for this study from the 1990 USGS and 1990 to 1993 WDOE reports are compared with historic data from the literature to extend time series data to March 1993. The parameter ranges from all data collected in this study are also compared with the historic data to relate the mean annual trends to the overall distribution of concentrations. A recent report on Columbia River water quality (Stober and Nakatani, 1992) summarized mean annual concentrations from three time periods: 1954 to 1959, 1975 to 1978, and 1981 to 1983. Only locations on the Columbia mainstem are included in this data set. Figures B–2, B–3, B–4, B–5, B–6, B–7, B–8, B–9, show the mean annual trends, and the minimum/maximum values for the study period (1974–1993) for the following parameters: conductivity, pH, nitrate/nitrite, ammonia, total phosphorus, dissolved oxygen.

In addition, the Corps provided secchi measurements taken in the fish ladder at Lower Granite Dam. These data showed a high correlation (r=.90) between the measured secchi depth and discharge (Figure B–10).

### Table B–1. Long-Term Monitoring Site Sampling/Analysis Frequency Summary

| River | Location | Cond. | DO | Hard. | NH3+NH4 | NO2+NO3 | OP | pH | S. Sed. | TP | Turb. | Site Avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Columbia | Warrendale | 2 | 2 | 1 | 1 | 2 | 1 | 2 | 2 | 2 | 1 | 1.6 |
| Columbia | Umatilla | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.0 |
| Columbia | McNary295 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0.8 |
| Columbia | Richland | 2 | 2 | 1 | 1 | 1 | 1 | 2 | 0 | 2 | 2 | 1.4 |
| Columbia | Vernita | 3 | 3 | 3 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 2.3 |
| Columbia | Rock Island | 3 | 3 | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 2.6 |
| Columbia | Grand Coulee | 3 | 3 | 1 | 3 | 2 | 3 | 3 | 3 | 3 | 3 | 2.7 |
| Columbia | Northport | 3 | 3 | 3 | 2 | 2 | 1 | 2 | 2 | 3 | 2 | 2.2 |
| Snake | Burbank | 3 | 2 | 2 | 1 | 2 | 1 | 3 | 2 | 3 | 3 | 2.2 |
| Snake | Ice Harbor RM 18 | 2 | 1 | 1 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 1.5 |
| Snake | Lower Monumental | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0.9 |
| Snake | Little Goose RM 83 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0.9 |
| Snake | Lower Granite RM 107 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0.9 |
| Snake | Lower Granite RM 120 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0.7 |
| Snake | Anatone, WA | 2 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1.0 |
| Snake | Weiser, ID | 3 | 2 | 1 | 1 | 1 | 1 | 2 | 1 | 2 | 2 | 1.6 |
| Clearwater | Spaulding RM 11.6 | 3 | 2 | 0 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 1.6 |
| Yakima | Kiona RM 29.9 | 3 | 3 | 0 | 2 | 1 | 1 | 3 | 3 | 3 | 3 | 2.2 |
| Yakima | Parker 37A190 | 3 | 0 | 1 | 0 | 0 | 0 | 3 | 3 | 0 | 3 | 1.3 |
| Spokane | Riverside State Park | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0.5 |
| Spokane | Near Post Falls | 3 | 0 | 1 | 0 | 0 | 0 | 3 | 2 | 0 | 3 | 1.2 |
| Pend Oreille | @Boarder62A080 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0.4 |
| Pend Oreille | @Newport | 3 | 0 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 4 | 1.0 |
| Whole Basin | Parameter Average | 2.1 | 1.4 | 1.1 | 1.0 | 1.0 | 1.0 | 1.9 | 1.4 | 1.4 | 1.9 | 1.4 |

3 = High (>6 per year)
2 = Med. (>=4 per year)
1 = Low (>0 per year)
0 = None (0 per year)

Table B–2. Basin Wide Water Quality Parameter Statistics (EPA, Storet, 1974–1992, all Columbia/Snake River Mainstem Data)

| Parameter | Unit | Number of Observations | Mean | Standard Deviation | Maximum | Minimum |
|---|---|---|---|---|---|---|
| Temperature | °C | 2,548 | 14.5 | 6.4 | 29.0 | 0.6 |
| Conductivity at 25°C | mho | 1,818 | 274.4 | 1,054.4 | 44,400 | 0 |
| Dissolved Oxygen | mg/l | 2,464 | 10.3 | 2.1 | 18.0 | 0 |
| pH | SU | 1931 | 7.9 | 0.5 | 13.1 | 6.1[1/] |
| Turbidity | JTU* | 483 | 3.8 | 4.1 | 30.0 | 0 |
|  | NTU | 931 | 7.8 | 17.8 | 250.0 | 0.1 |
| Total Hardness | mg/l as $CaCO3$ | 525 | 64.0 | 13.9 | 120 |  |
| Nitrate plus Nitrite | mg/l N-total | 1,036 | 0.175 | 0.298 | 4.80 | ND[2/] |
| Ammonia ($NH3+NH4$) | mg/l N-total | 1,114 | 0.054 | 0.124 | 2.300 | ND[2/] |
| Total phosphorus | mg/l | 1,939 | 0.067 | 0.236 | 7.480 | ND[2/] |
| Orthophosphate | mg/l Dissolved | 1,343 | 0.033 | 0.230 | 6.79 | ND[2/] |
| Suspended sediments | mg/l | 420 | 23.4 | 73.2 | 815 | 0 |

* Use Of JTU Units ended 7/86.
1/ Minimum pH does not include outliers reported at Northport, WA, Kiona, WA and Spaulding, ID.
2/ Reported as zero but assumed to mean not detected.

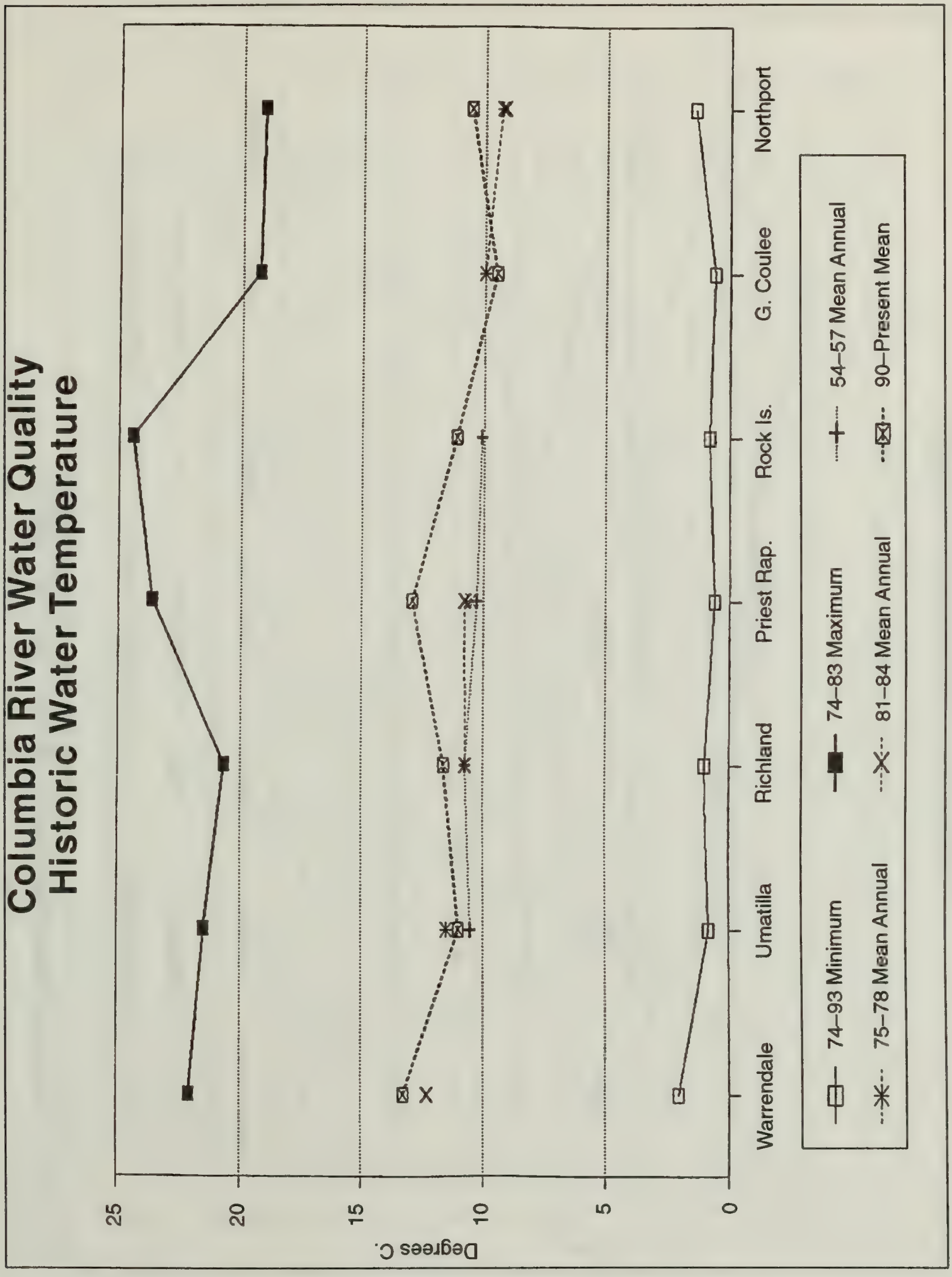

**Figure B–2. Columbia River Water Quality Historic Water Temperature**

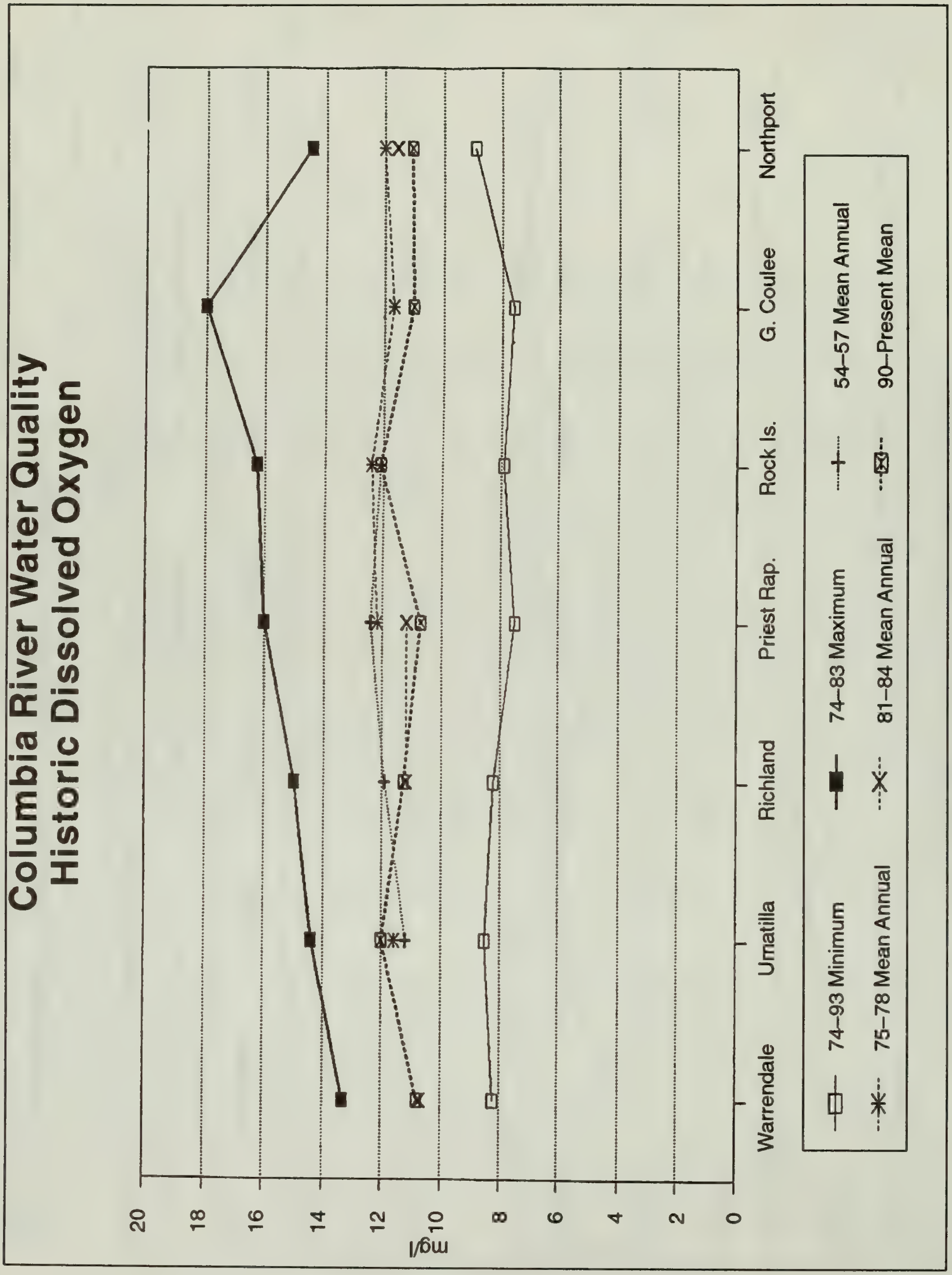

**Figure B–3.** Columbia River Water Quality Historic Dissolved Oxygen

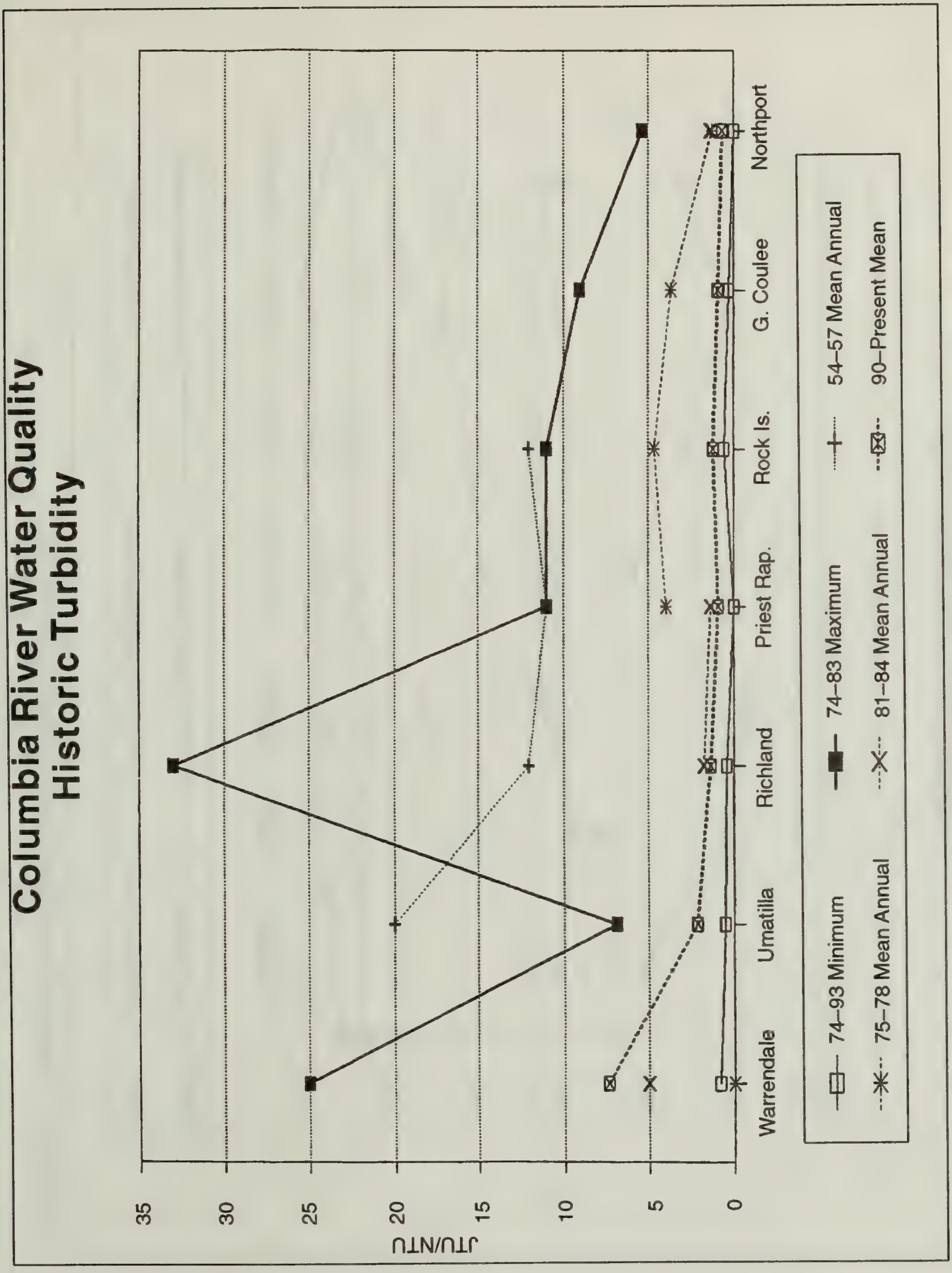

**Figure B–4.** Columbia River Water Quality Historic Turbidity

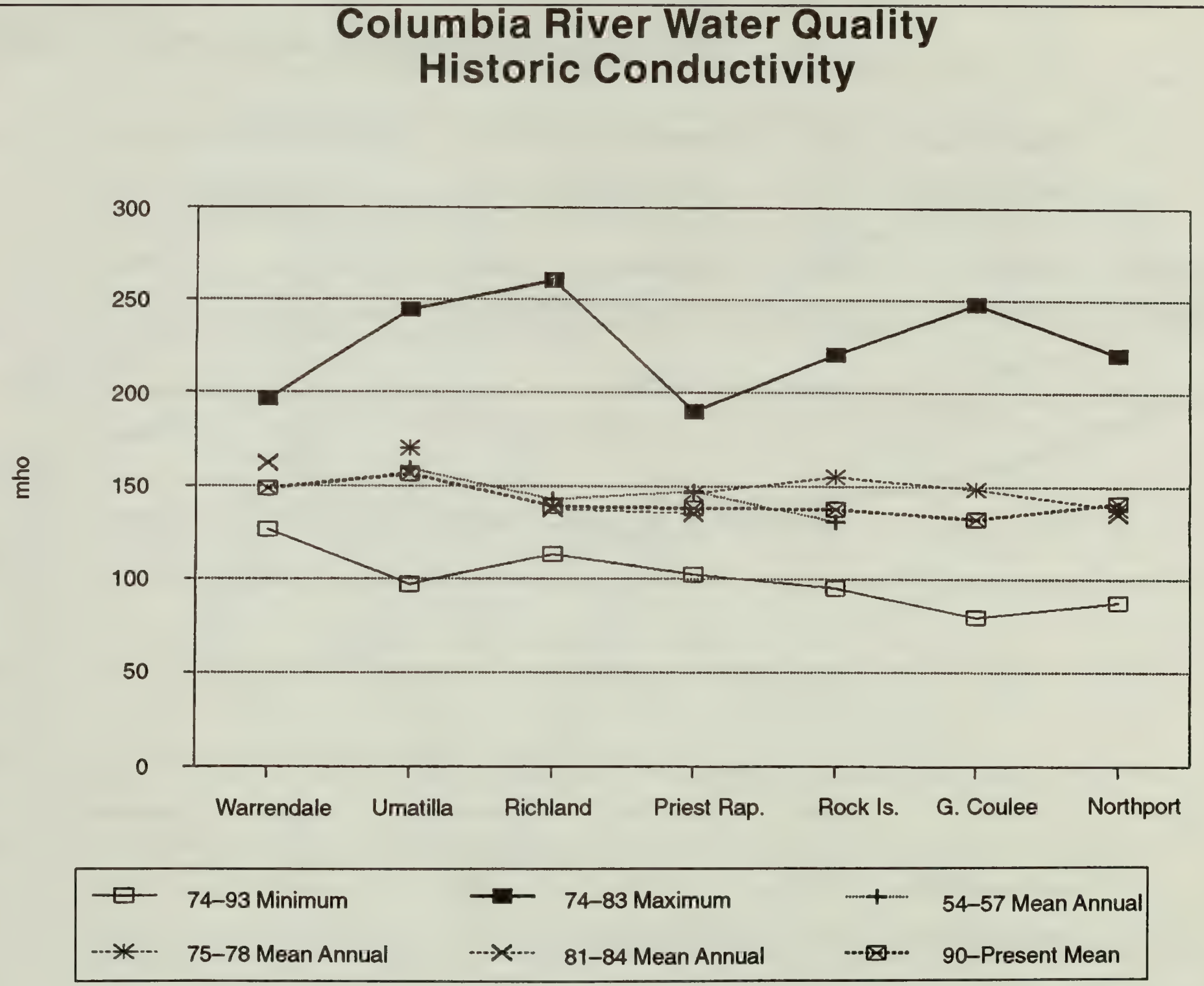

**Figure B–5.** Columbia River Water Quality Historic Conductivity

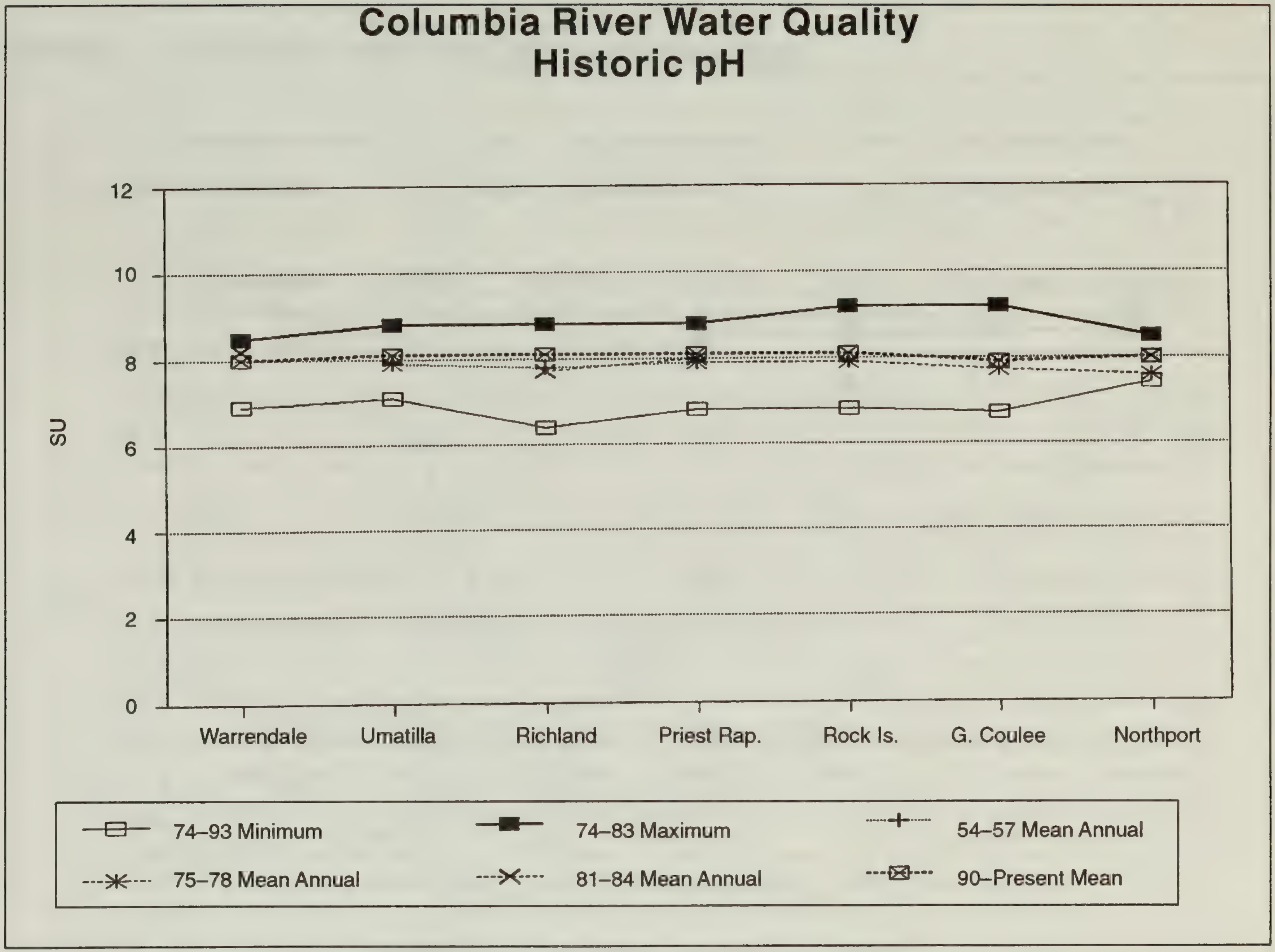

Figure B–6. Columbia River Water Quality Historic pH

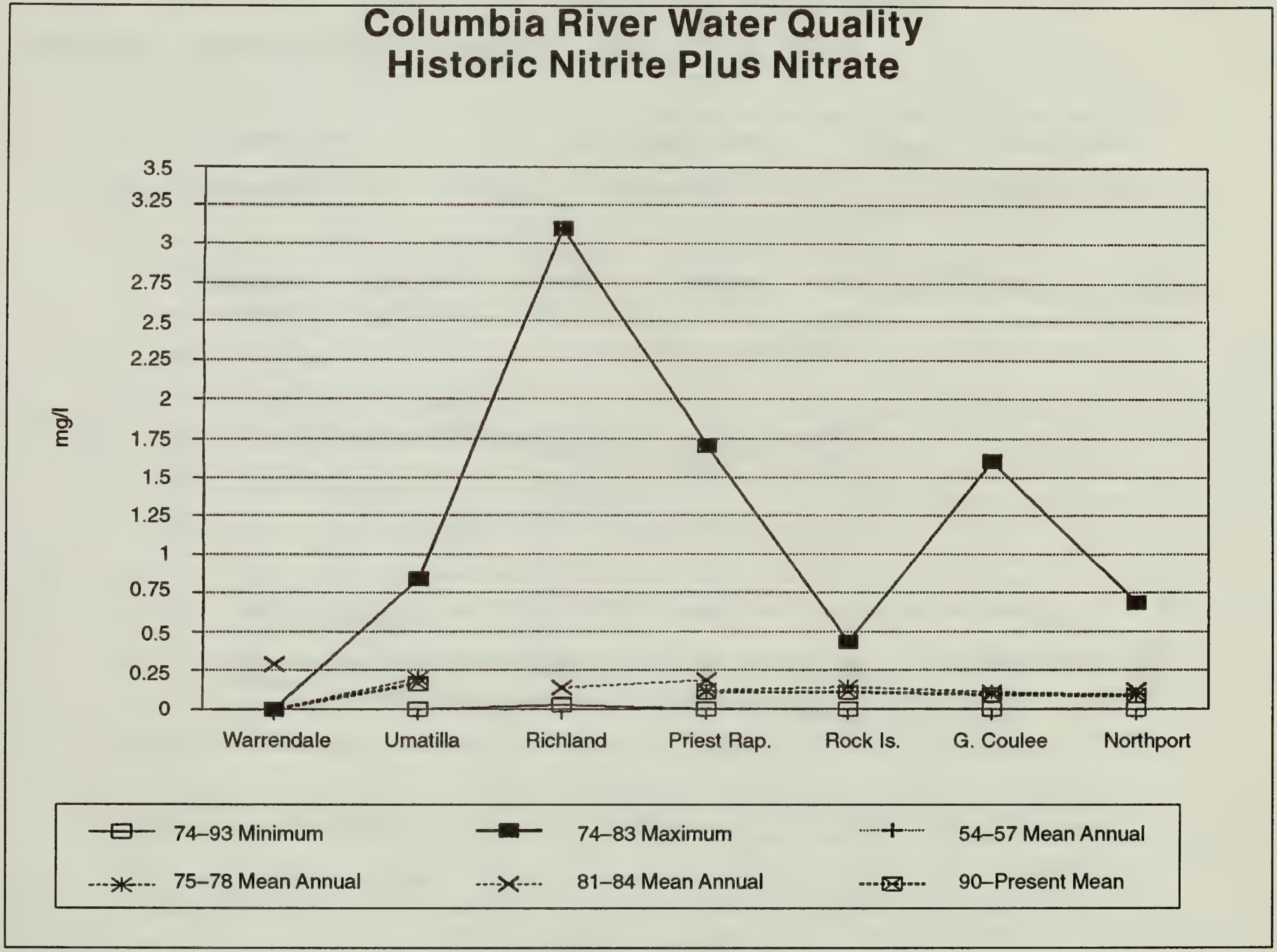

Figure B–7. Columbia River Water Quality Historic Nitrite Plus Nitrate

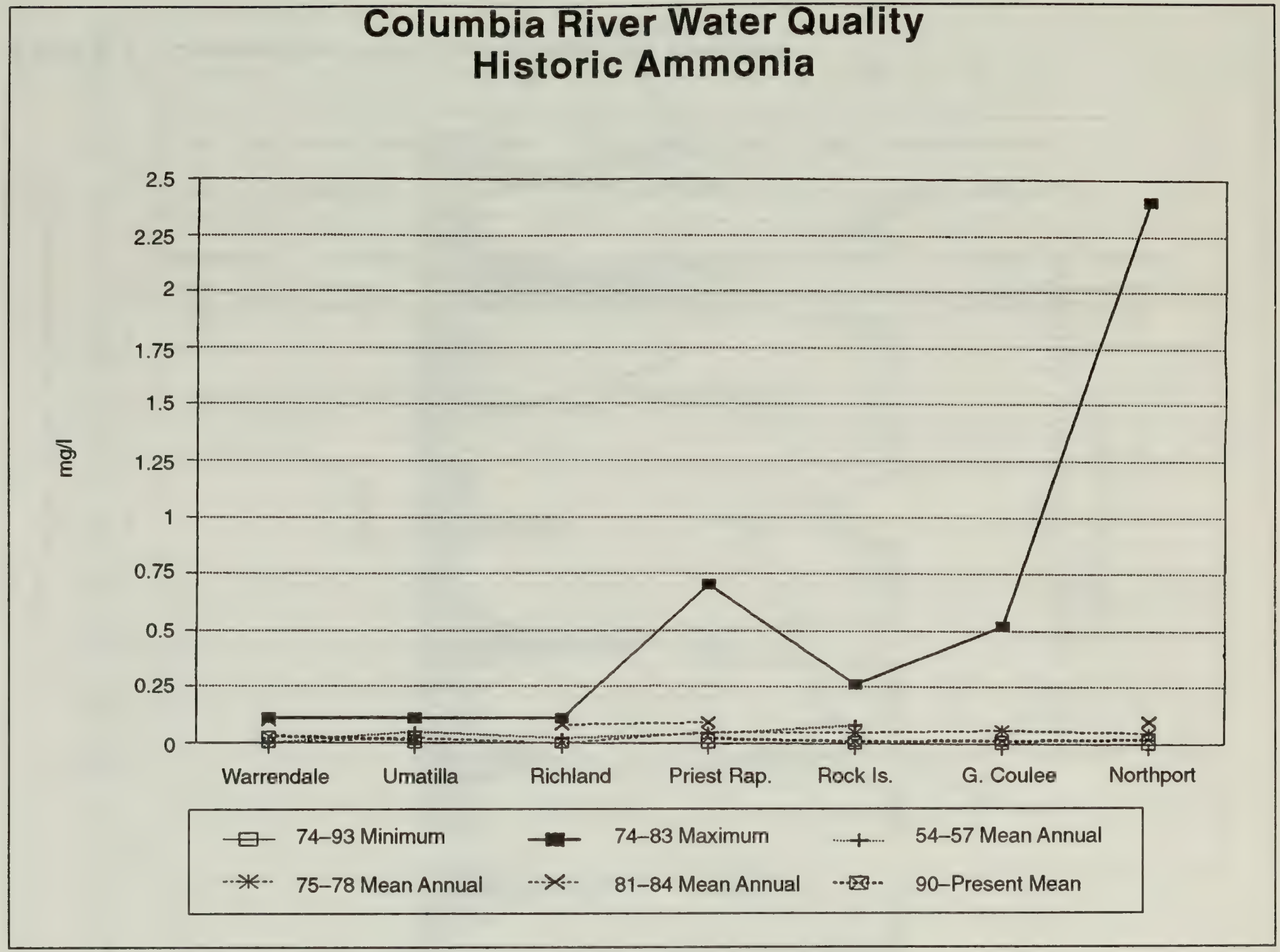

**Figure B–8.** Columbia River Water Quality Historic Ammonia

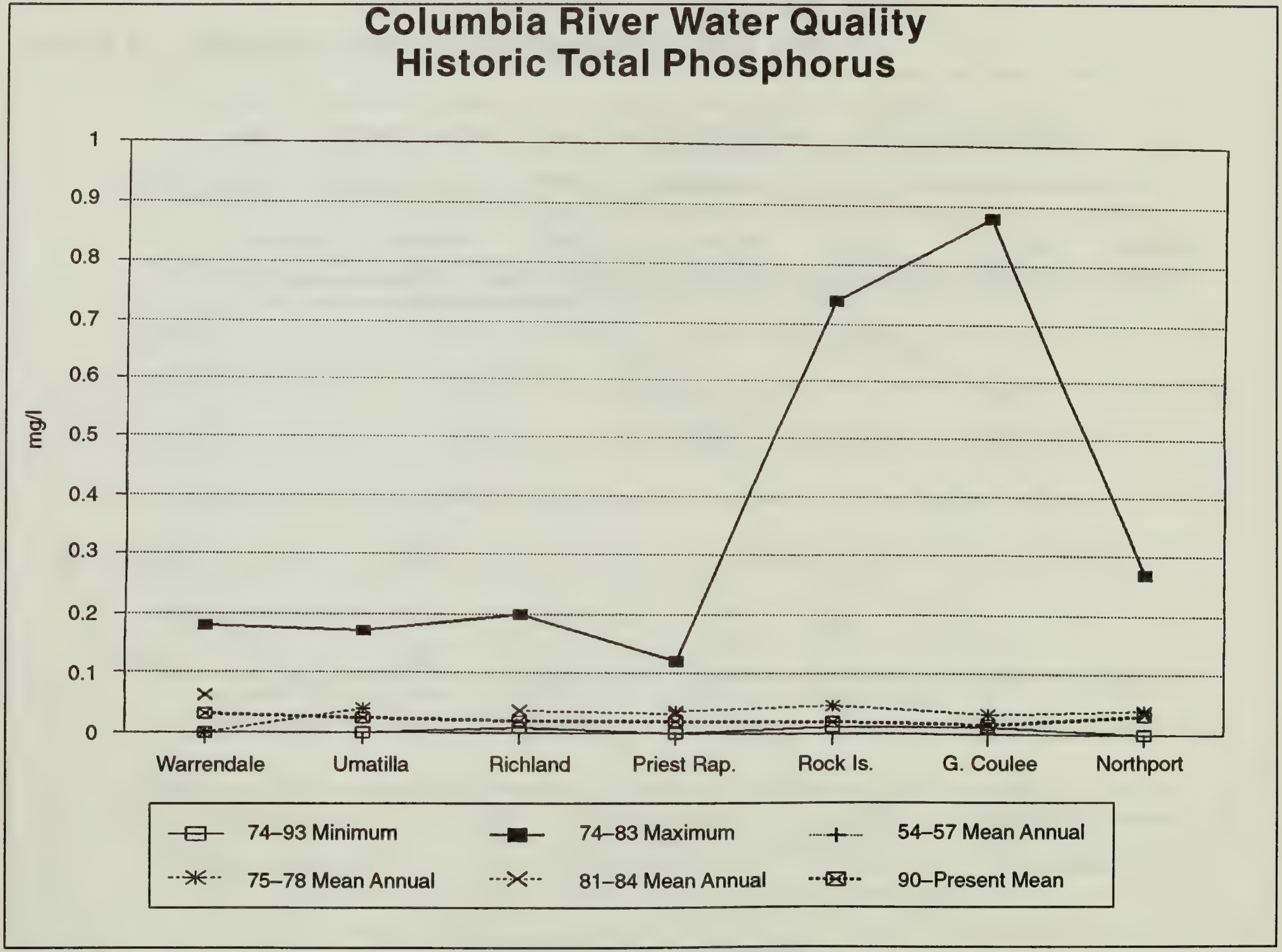

Figure B–9. Columbia River Water Quality Historic Total Phosphorus

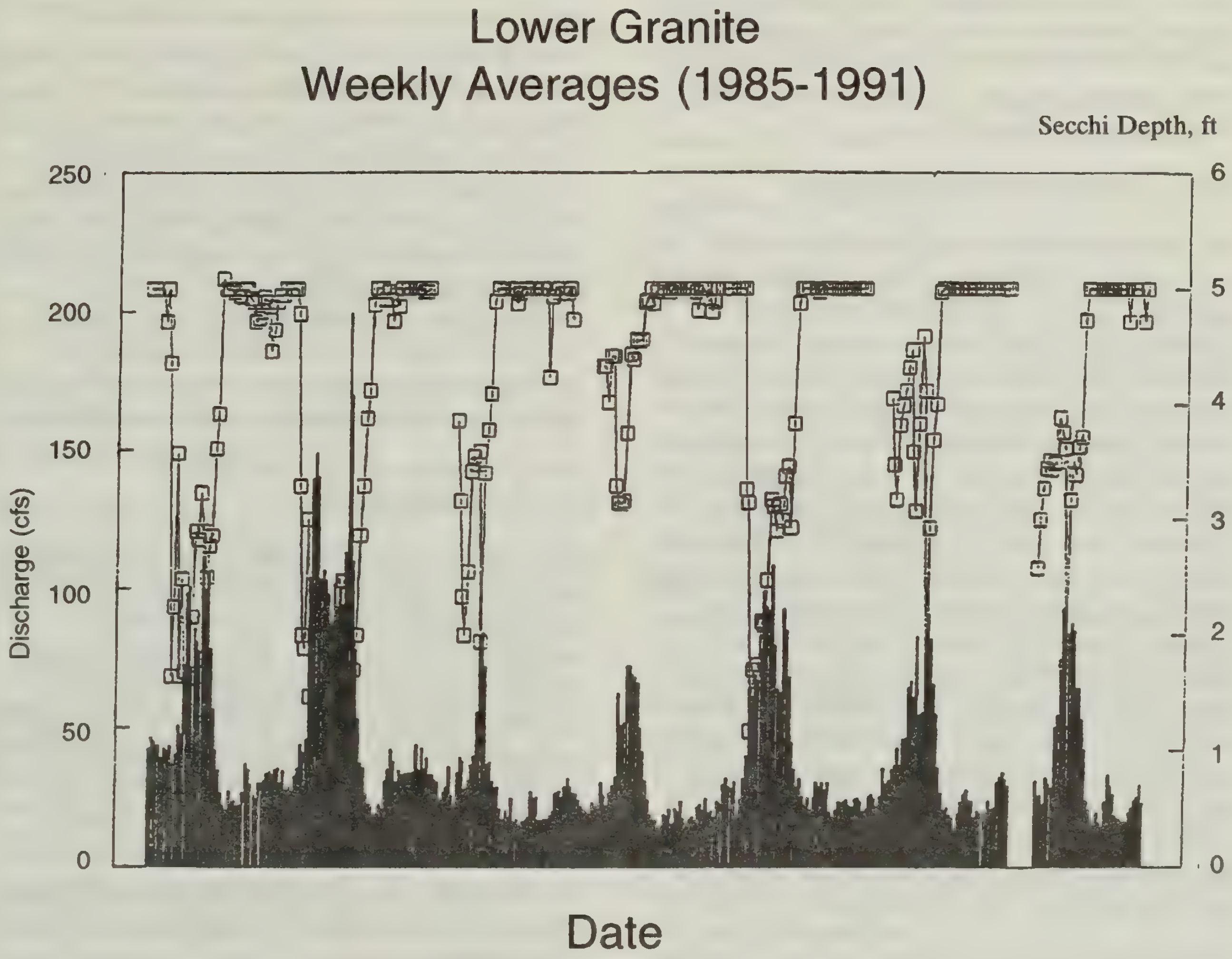

Figure B–10. Mean weekly secchi depth[1] and river discharge at Lower Granite Dam.

[1] As measured in the fish ladder.

## B–6 DISCUSSION

The discussion of the water quality characterization of the Columbia River Basin is directed towards a description of the amount and usefulness of existing data, a comparison of water quality criteria with the range of parameters values observed in specific mainstem and tributary reaches, and a review of recent studies performed on the Lower Columbia downstream of Bonneville Dam.

### B–6.1 EXISTING DATA ADEQUACY

The data review in this study were evaluated for their usefulness in describing existing conditions, analyzing historic trends, and predicting future conditions given changes in the system operation. Previous whole–basin water quality studies required the data to provide a synoptic picture of the river (Rickert, Hines aid McKenzie, 1976). The databases reviewed in this study did not contain many long–term monitoring stations throughout the whole Columbia River basin. In addition, there were many gaps the long–term monitoring throughout the study period from 1974 to present. Larger spatial and temporal gaps in the historic data (pre–1974) were found in the literature. The data from the limited long–term monitoring stations provided an incomplete picture of the water quality within the system. It is reasonable to infer from the sparsity of data that no sampling program implemented in the Columbia Basin was designed to provide a basis for the prediction water quality throughout the entire river system.

These water quality data deficiencies were probably a result of the purpose of the collection programs. In many basins the existing river quality database has been compiled largely through pollution monitoring and surveillance programs (Rickert, Hines and McKenzie, 1976). In general, the Columbia River databases exhibited this. The USGS monitoring stations were the most continuously sampled. The Corps and EPA databases had many sampling date and location gaps. The WDOE Ambient Monitoring Program was designed to monitor water quality background conditions over the long term, but not to focus on system–related cause and effects. Most of the databases contain monitoring and surveillance data that were collected to detect symptoms of water quality problems, and not to make inferences about any long term, systematic effects that were caused by specific sources.

Predictive studies requiring more intensive data for water quality model calibration and validation would need an additional sampling program to produce results of high spatial and temporal accuracy. In the absence of a more synoptic water quality data set, the existing data is most useful for planning level modeling of system–wide water quality. The range of parameter concentrations observed at long–term stations provides a sufficient level of detail for predicting and comparing the relative effects that alternative future system operations impose on water quality. Generally, a qualitative description of existing conditions is provided by the existing data.

### B–6.2 BASIN–WIDE ANALYSIS OF PARAMETERS

The number of samples collected and the parameters analyzed varied between stations, therefore only the data collected at the long–term stations are included in this discussion. For reference purposes, the Columbia River is divided into three reaches: the lower, middle and upper. The lower reach begins at Bonneville Dam and ends at the Snake River. The middle reach extends upstream to, but does not include Grand Coulee. The upper reach ends at Northport, which is the farthest upstream monitoring site in the U.S.. Water quality criteria are stated where applicable, and critical trends and exisiting are indicated.

#### B–6.2.1 Dissolved Oxygen

The minimum EPA standard for dissolved oxygen (DO) is 8.0 mg/l. The Snake River minimum DO levels for the entire the study period, at all long–term stations, were below this standard. The Snake River showed the lowest DO concentration in the study area. The lowest minimum DO was 2.3 mg/l at Lower Granite Dam (river mile 107). The Clearwater at Spaulding, Idaho also showed all excessively low level of 4.8 mg/l. Upstream at Weiser, Idaho the minimum was 5.8 mg/l. This minimum DO level is about average for the observed minimum in the Snake River further downstream. The minimum DO at Burbank, Washington (near the mouth) was 6.2 mg/l. WDOE observed increasing mean DO on the Snake River from Lower Granite (7.8 mg/l) to Ice Harbor (9.5 mg/l).

DO in the main–steam Columbia River rarely declines below the minimum standard (Stober and Nakatani, 1992). Downstream of the Snake confluence, McNary minimum DO was still below the standard at 6.7 mg/l, but increases above the standard by Umatilla. DO minimum levels were within standards at Richland, but slightly below at Vernita and Rock Island. Grand Coulee minimums were also slightly below standards, but never so at Northport.

The DO levels below the 8.0 mg/l standard were observed in the Yakima River at Kiona, and in the Kootenai River below Libby Dam.

DO concentration in the Columbia River are highest during spring runoff in May and June. Surface waters generally have higher concentrations of DO than deeper layers in storage reservoirs. In most mainstem Columbia River reservoirs rapid flushing and limited stratification usually prevent low DO levels (Stober & Nakatani 1992). Snake River reservoirs showed evidence of depressed DO levels during minimum streamflows in August and early fall, and low DO levels in the hypolimnion layer of Brownlee Reservoir.

Historical trends plotted in Figure B–2 show a change in the longitudinal profile of mean annual DO concentrations after the mid–1970 between Rock Island and Umatilla. The 1950's and 1970's profiles show DO levels peaking at Priest Rapids, then steadily declining to Umatilla. The later profiles peak at Rock Island and Umatilla, with a sag at Priest Rapids (Vernita), and a decline towards Warrendale. While there are only 14 mean annual data points that show this change, the data suggest an increase in oxygen demand or a decrease in reaeration, or both, in the reach between Priest Rapids and Rock Island after 1974. Higher mean annual water temperatures may also account for the lower 1990 DO levels near Priest Rapids. A combination of high temperature meteorologic conditions, irrigation withdrawals and low flows, and return flows laden with sediment, nutrients and organic matter in the middle Columbia and lower reaches of its tributaries enhance the decline of DO levels there (Stober and Nakatani, 1992).

#### B–6.2.2 Turbidity and Suspended Sediments

Dams on the Columbia River temporarily slow the downstream flow of sediment, but fine sediments deposited in the reservoirs are resuspended during high flows and passed downstream (Stober & Nakatani 1992), as illustrated by the observed correlation between decreasing secchi measurements and increasing river discharge (Figure B–10). The U.S. Fish and Wildlife Service also found a strong negative correlation between flow and visibility, and spill and visibility at all the Lower Snake River Dams (Bjornn and Rubin, 1993). Suspended sediment loads, as indicated by mean annual turbidity, have decreased from 10–20 NTU in 1954–57 to less than 5 NTU since 1975 (Figure B–11).

The installation of dams on the main steam and tributaries since the mid–1950 may explain this.

The maximum turbidity on the Columbia since 1974 was 33 NTU at Richland. WDOE observed the maximum Columbia River mean turbidity of 4.6 NTU's at Warrendale. The maximum on the Snake was 150 JTU at Burbank and Ice Harbor. This unusually high level was reported only once for the lower Snake, in December of 1977. WDOE observed the maximum Snake River mean turbidity of 5.0 NTU at Ice Harbor Dam.

More commonly, turbidity is higher in the tributaries than in the mainstem Columbia or Snake. WDOE observed a mean turbidity of 8.5 NTU on the Yakima River at Kiona. The maximum at the mouth of the Clearwater and Yakima Rivers are at least four times greater than the Columbia River at Richland. Riverside State Park on the Spokane River has the highest reported turbidity at 210 NTU. Unlike the Yakima River, the Spokane River mean turbidity observed by WDOE is only 1.4 NTU.

Suspended sediments are sampled less frequently than turbidity, but the existing data show the maximum tributary concentrations are two to four times greater than the maximum on the mainsteams. Rock Island and Umatilla stations on the Columbia report concentrations greater than 300 mg/l, and the lower Snake reports greater than 200 mg/l. The Clearwater and Spokane Rivers report maximums near 1200 mg/l. The Yakima at Kiona and Flathead report around 500 mg/l.

Low maximum suspended sediment concentrations are more typical in the mainstem Columbia and in the upper reaches of the tributaries. Data on the Snake are scarce. The extremely low maximum are reported at Grand Coulee and Northport on the Columbia and at Newport on the Pend Oreille River.

### B–6.2.3 Conductivity/Salinity/Hardness

Water in the Columbia River is a dilute calcium–magnesium carbonate–bicarbonate type with a total dissolved solids content of about 90 mg/l (range 71 to 158 mg/l) from the international boundary downstream to the confluence of the Snake River (Ebel et al. 1989). The mean total hardness of the Columbia and Snake mainsteams for the study period is 64.0 mg/l (as $CACO_3$). Conductivity generally increases with progression downstream from Northport to Warrendale on the Columbia. Hardness generally increases in the tributaries from Parker to Kiona on the Yakima, from Post Falls to Riverside State Park on the Spokane, and from Newport to the Border station on the Pend Oreille.

Most of the conductivity increase in the Columbia is due to the high–conductance inflows from the Snake River, as shown by the historic trends plot in Figure 2.D between Richland and Umatilla. Conductivity in the Snake River ranges from 63 to 681 µmhos with an slight decrease in mean conductivity from Lower Granite Dam (184.8 µmhos) to Lower Monumental Dam (171.5 µmhos), with an increase further downstream at Ice Harbor Dam (193.3 µmhos). High conductivity is also found in the Yakima and Spokane Rivers. A more pronounced pattern of increasing downstream conductivity is exhibited by the Yakima River (Figure B–11). Increases in Columbia River conductivity that occur downstream of the confluence of the Snake River (RM 324) with the Yakima River (RM 335) are probably due to increasing salts and ions in irrigation return flows.

### B–6.2.4 pH

The pH levels on the main stein Columbia, Kootenai, Flathead, and Yakima rivers are within the standard 6.5 – 8.5 range and do not change appreciably downstream. The pH levels on the Snake River appear to be slightly higher, with an occasional maximum of 9. 1, although the yearly averages remain within the standard range.

Three extremely low pH measurements are reported. Northport on the Columbia, Spaulding on the Clearwater, and Kiona on the Yakima all reported a pH of below 1. This is probably a measurements error. But quality control of the databases becomes an issue when errors like these are not detected.

### B–6.2.5 Ammonia

The EPA chronic freshwater standard for un–ionized ammonia ($NH_3$) is dependent on pH and temperature. The standard is based on salmonid fish. Ten times the lowest lethal concentration of $NH_3$ for rainbow trout fry is 0.2 mg/l (Viessman and Hamiller, 1985). $NH_3$ concentration in water cannot be measured, so the measured value of $NH_3+NH_4$ is used as a reference. For a pH of 8.5 and a temperature of 20.0 C, the criterion level for an equivalent total ammonia is 0.32 mg/l (Tetra Tech, 1992). Total ammonia is reported in this study and is referred to as "ammonia". All stations on the Columbia historically show ammonia concentrations below the standard. The only Columbia stations to report maximums in exceedence of the standard are Priest Rapids, Grand Coulee and Northport. The maximum of 2.4 mg/l at Northport is over three times greater than the next highest reported maximum at Priest Rapids. WDOE observed a mean $NH_3$–nitrogen range of 0.02 mg/l to 0.04 mg/l in the Columbia River.

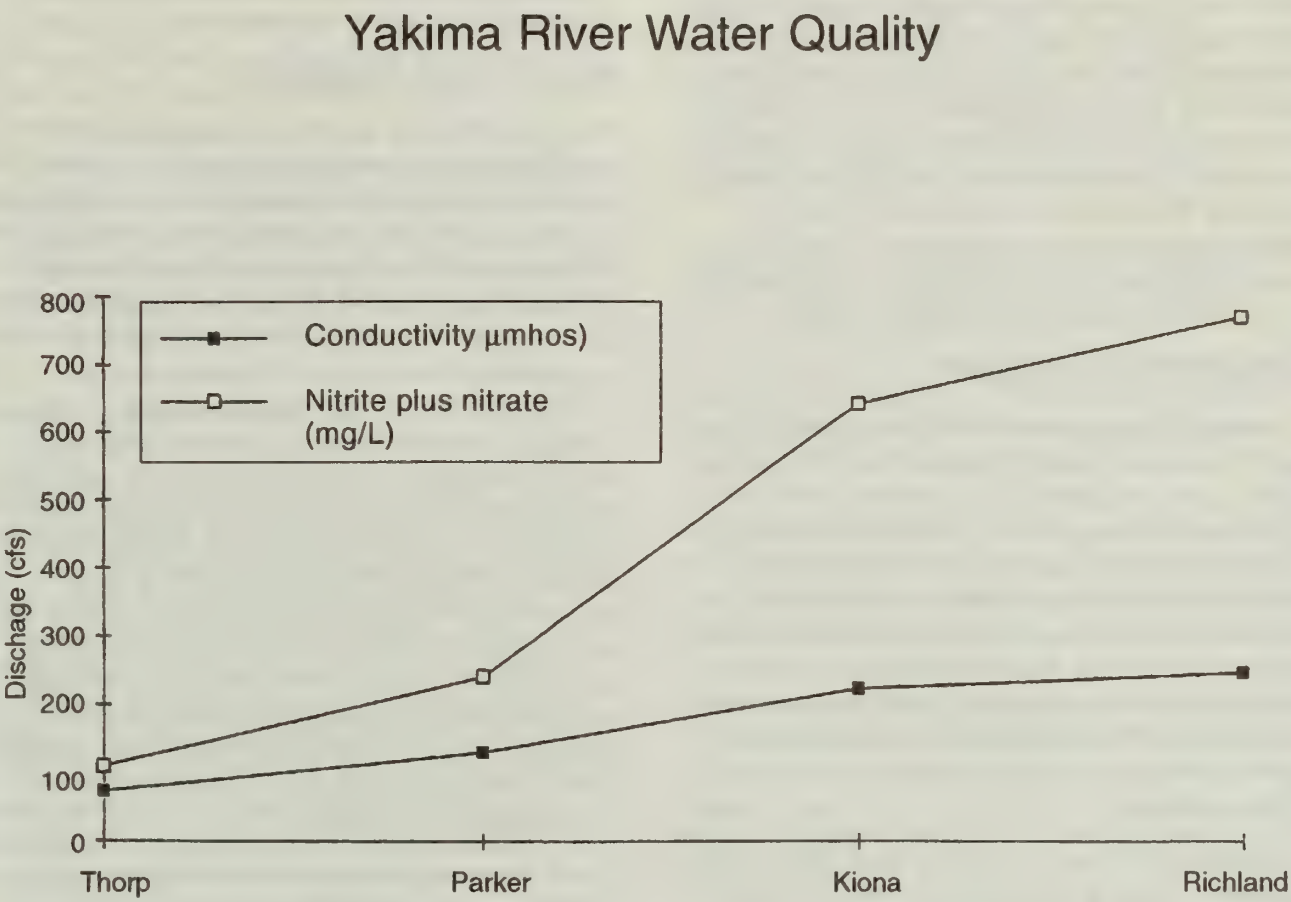

**Figure B–11. Yakima River Conductivity and Nitrite Plus Nitrite Profile.**

Ammonia sampling on the Snake is scarce. Only Burbank is sampled regularly throughout the study period. The EPA reports frequent sampling for ammonia in the Snake, but only from 1975 to 1977. The Corps sampling during this time period detected mean station ammonia concentrations ranging from 0.016 mg/l to 0.163 mg/l (Funk et al., 1979). The maximum Snake ammonia content detected during this period was 0.75 mg/l, reported at Lower Granite (river mile 107). The Clearwater station at Spaulding, Idaho reported an exceedingly high maximum of 2.2 mg/l, though Kiona on the Yakima had the highest ammonia concentration in the basin at 2.9 mg/l. High ammonia levels may be due to municipal or industrial wastewater treatment discharges.

### B–6.2.6 Nitrite Plus Nitrate

Nutrient loadings, as indicated by $NO_2$+$NO_3$ (mg/l as N), historically show a trend of decreasing mean annual concentrations in the Columbia River from the Canadian border to the mouth. Nitrate–nitrogen observed maximums at all Columbia River stations exceed 0.3 mg/l (critical level for algae blooms), but the mean annual concentrations remain below critical levels. The EPA drinking water standard for nitrate is 10 mg/l, and there are no reported exceedences. WDOE observed a mean $NO_2$+$NO_3$ level of 0.08 mg/l at Northport and 0. 14 mg/l at Warrendale.

The maximum nitrite plus nitrate level of the Snake is about 1.5 mg/l at all stations, but the Clearwater at Spaulding station reached a maximum of 3.9 mg/l. Kiona on the Yakima reported a maximum of 1.9 mg/l. On the Columbia, Richland reported the highest concentration at 3.1 mg/l. These elevated concentrations may be due to municipal or industrial wastewater treatment plant discharges.

Seasonal cycles in nitrite plus nitrate are typical. Algae blooms in the spring are a naturally occurring phenomenon, but they may be increased by the river system impoundments. WDOE reports on Umatilla show that maximum levels are typically reached in March. The maximum at Umatilla was 0.84 mg/l, recorded March 14, 1979. The mean concentration at Umatilla is 0.1 mg/l, whereas the mean of the mainsteam Columbia and Snake is 0.175 mg/l. Minimum concentrations are observed during the summer when biologic uptake is at its height.

Sparse nutrients exist in the headwater reaches of the basin. The lowest maximum concentrations observed in the whole basin were found in the Flathead and Kootenai river stations.

### B–6.2.7 Ortho–Phosphorate

The Corps–funded study of the Snake River impoundment series limnology (Funk et al., 1979), explains the processes of dissolved ortho–phosphate (OP) transport from a free–flowing river into and through a reservoir. Upstream of Lower Granite Reservoir the mean OP content was higher than in the reservoir. According to this study, the OP concentration was reduced in the reservoir due to the dilutory effect of the Clearwater River water, biological uptake by aquatic plants including algae, and the settling of absorbed phosphate on sediments and detritus in the more quiescent reservoir waters. The mean OP content ranged from .006 mg/l to 0.038 mg/l. The three year mean water column concentration was 0.020 mg/l (Funk et al., 1979). As is the case with nitrite plus nitrate, seasonal trends are strong. The highest OP levels occur at the start of high runoff in the spring, and in the late fall at the end of the low–flow season. High levels are also encountered during the winter months, when biologic uptake is at its lowest.

Mean annual concentrations of OP observed by the USGS exceeded 0.01 mg/l (critical level for algae blooms) at all Columbia mainstem stations and in the Snake, Clearwater and Yakima rivers. The Flathead and Kootenai river ortho–phosphate levels remained below critical levels.

### B–6.2.8 Total Phosphorus

Total phosphorus (TP) includes dissolved OP and other forms of phosphorus. WDOE observed mean TP levels on the Columbia River that are three times greater than mean OP levels, with maximum occurring during winter and spring. The majority of phosphorus is likely attached to particulate matter. Thus it should settle out of suspension in reservoirs and resuspend during high flow. The Corps measured TP content from 1975 to 1977 in the Snake

River (Funk et al., 1979). The minimum reported was 0.010 mg/l, and the maximum was 0.320 mg/l. The reported annual means ranged from 0.04 mg/l to 0.11 mg/l.

Columbia mainstem station maximums were highest at Grand Coulee at 0.88 mg/l, and at Rock Island at 0.74 mg/l. Tributary maximum were 0.57 mg/l at Kiona on the Yakima, 0.49 mg/l at Spaulding on the Clearwater, 0.26 mg/l at Libby on the Kootenai, and 0.05 mg/l near Columbia Falls on the Flathead. The low maximum value suggests nutrient deficiencies in the Flathead River. The high maximums at Grand Coulee and Rock Island suggest algal blooms. Fertilizers washing off the Yakima Valley agricultural land probably account for the high level at Kiona.

### B–6.3 LOWER COLUMBIA

Conventional and nutrient water quality parameters were investigated in a recent Lower Columbia River Bi–State Program Reconnaissance Survey (Tetra Tech, 1992). Forty–five samples were taken at locations between the mouth and river mile 146 (below Bonneville Dam) for that study. The Bi–State program analyzed samples for many of the same conventional and nutrient water quality parameters addressed in this study, including temperature, conductivity, DO, pH and turbidity. The nutrient parameters that were analyzed by both studies included combined nitrate and nitrite nitrogen, ammonia nitrogen, and total phosphorus.

The Bi–State Program draft report discussed the significance of the influence of nutrients on nuisance growths of algae. It noted that previous studies did not observe large masses of algae, even when nutrients were present at levels sufficient to promote growth during the critical low–flow period. The report concluded that algal biomass in the Columbia River mainstem appears to be controlled by the production and release of these algae in river system impoundments. The report identified the increasing springtime abundance of diatoms in the upstream reservoirs that washed downstream with the season's high discharges as cause of peak phytoplankton biomass and abundance in the lower Columbia River, and not nutrient discharges in that reach (Tetra Tech, 1992).

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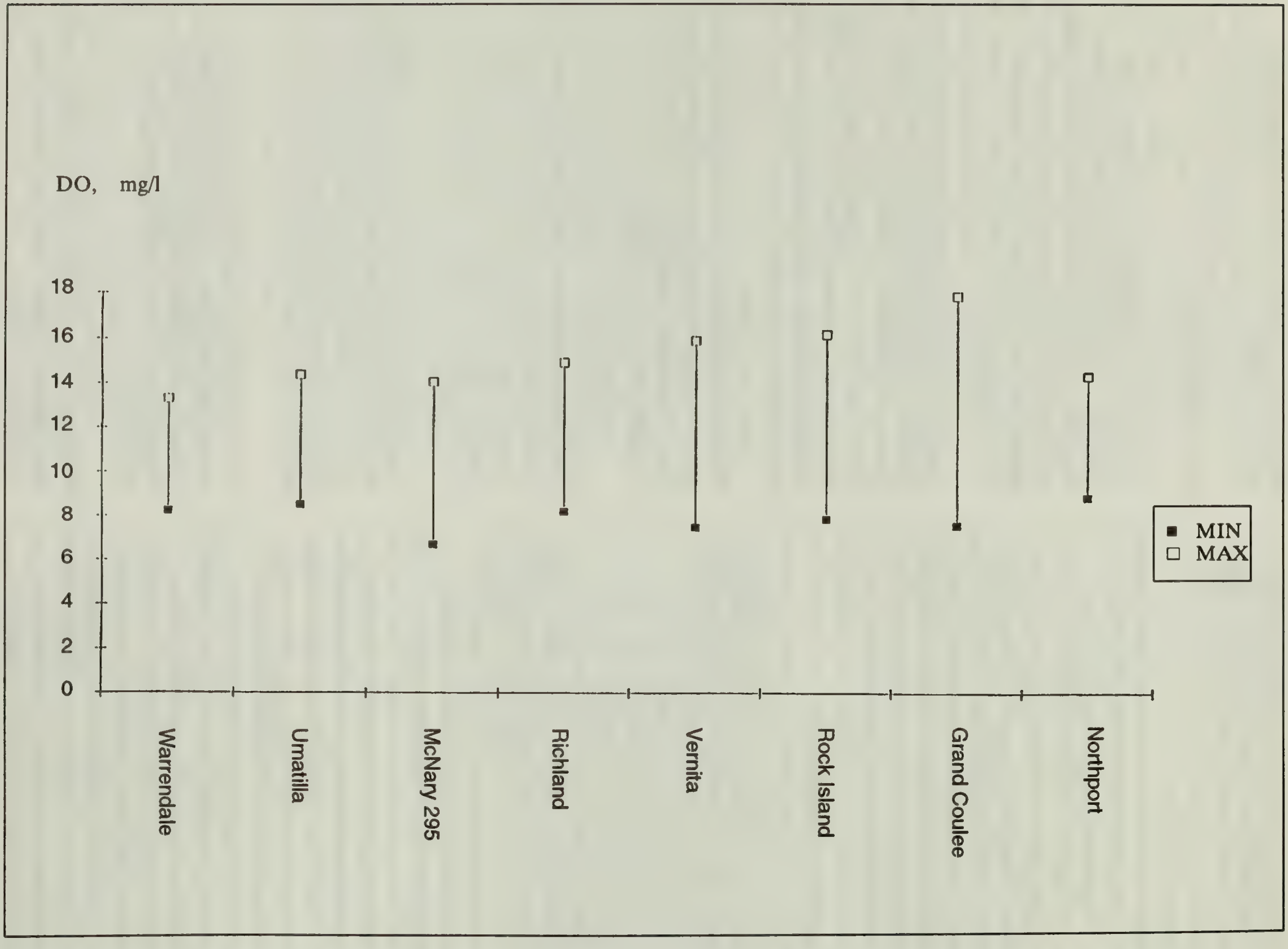


Figure B–12. Columbia River DO (mg/l)

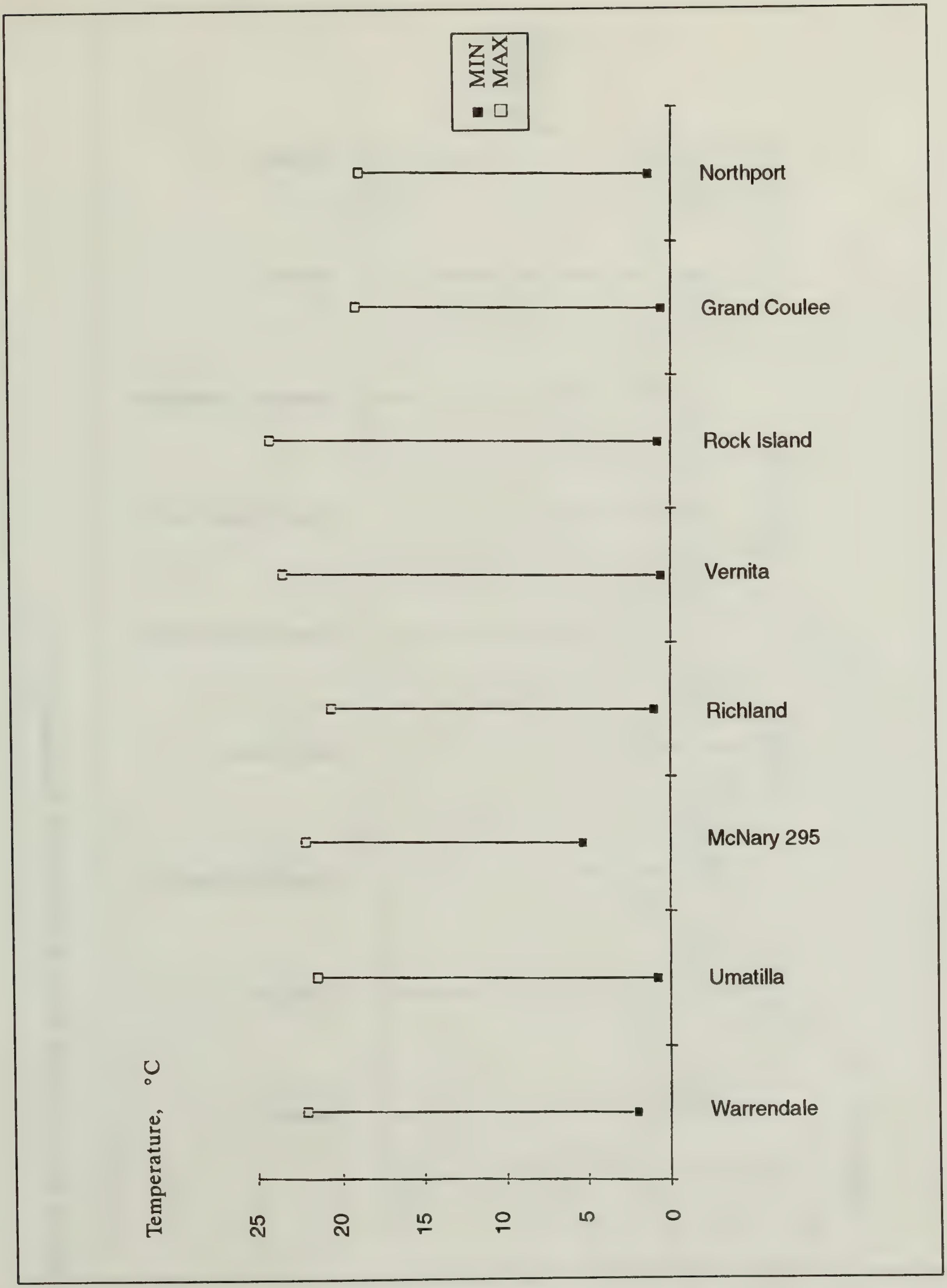


Figure B–13. Columbia River Temperature (°C)

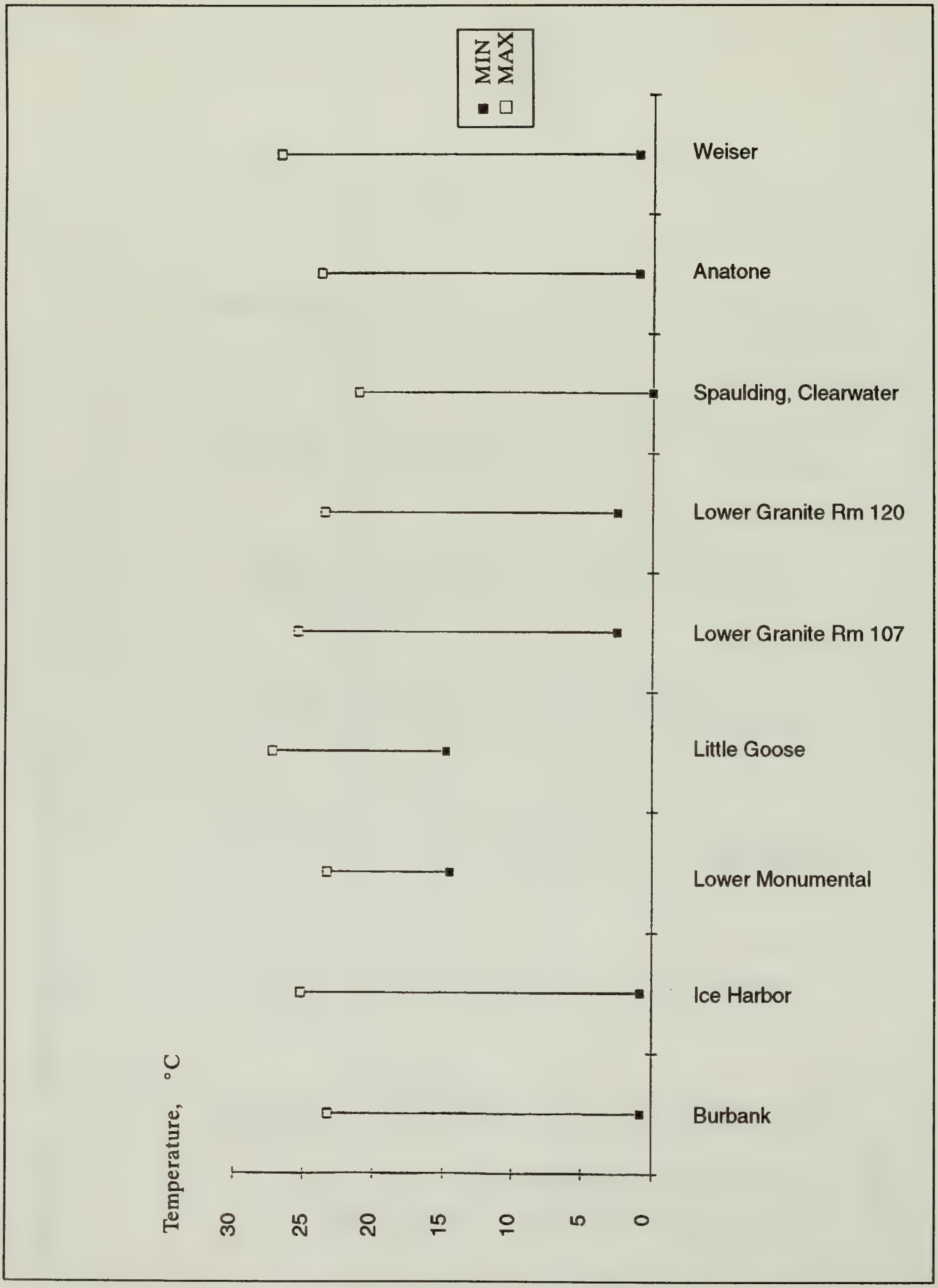


Figure B–14. Snake River & Clearwater Temperature (°C)

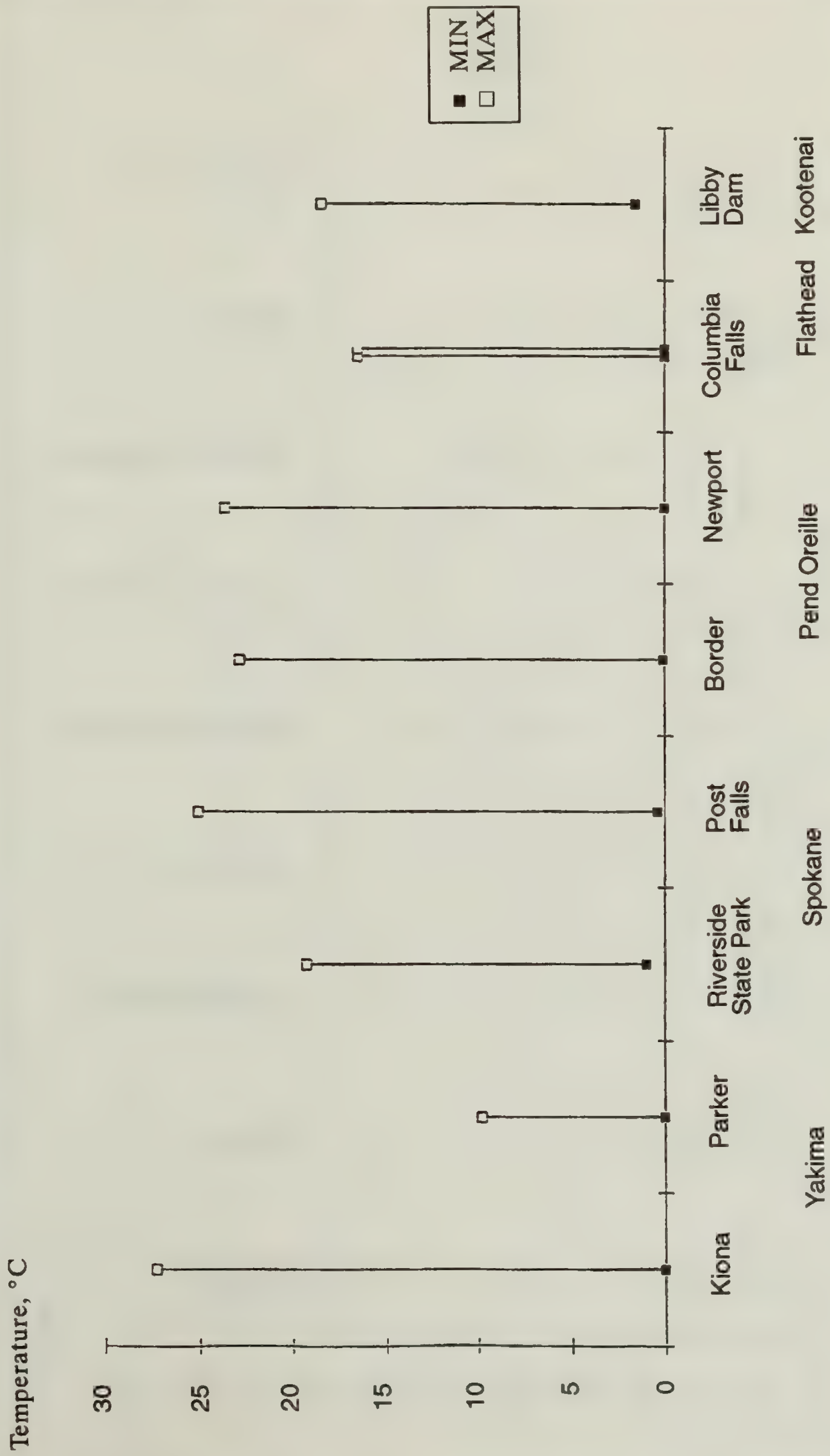


**Figure B–15. Tributaries Temperature (°C)**

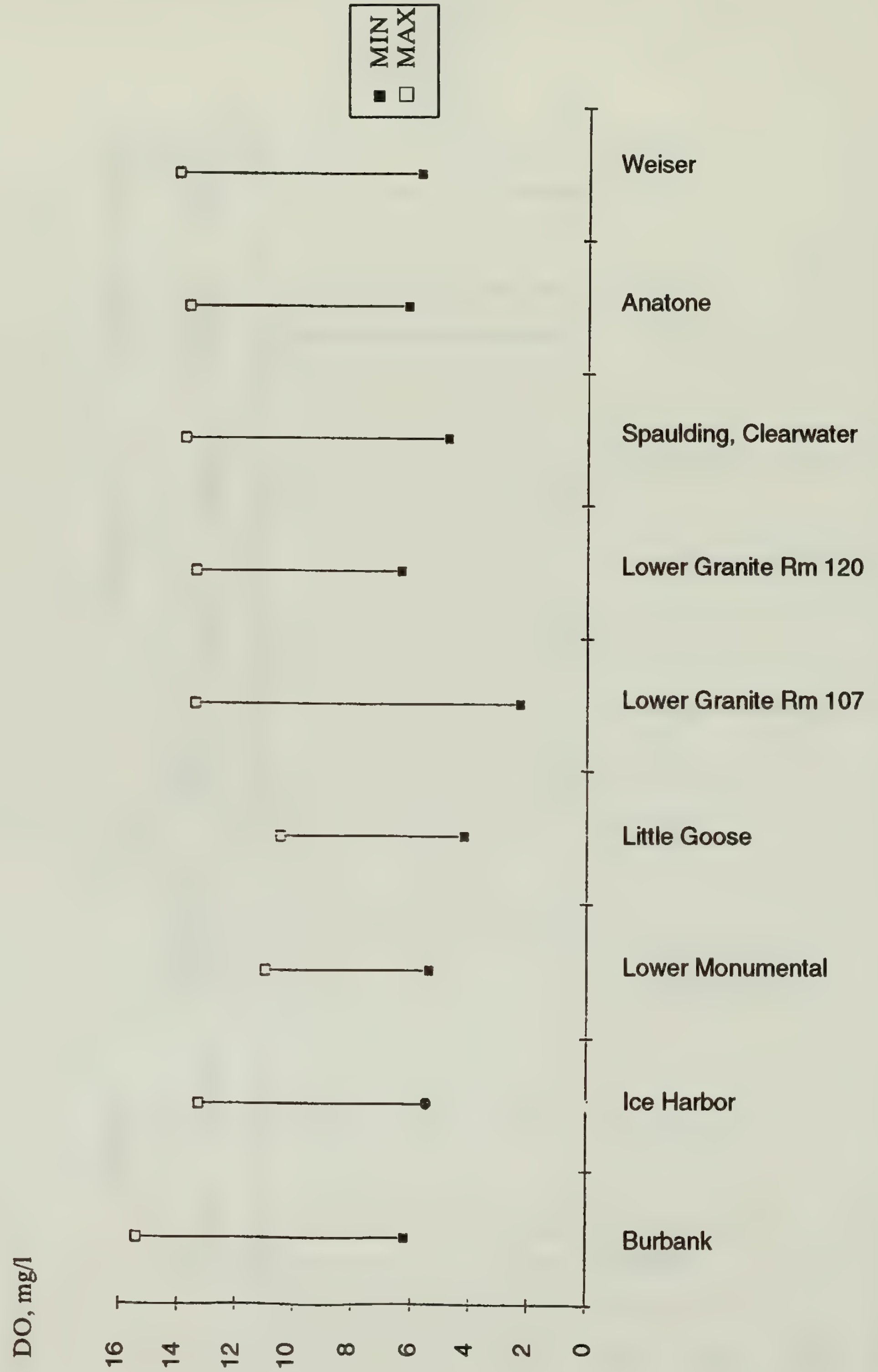


**Figure B–16. Snake River & Clearwater DO (mg/l)**

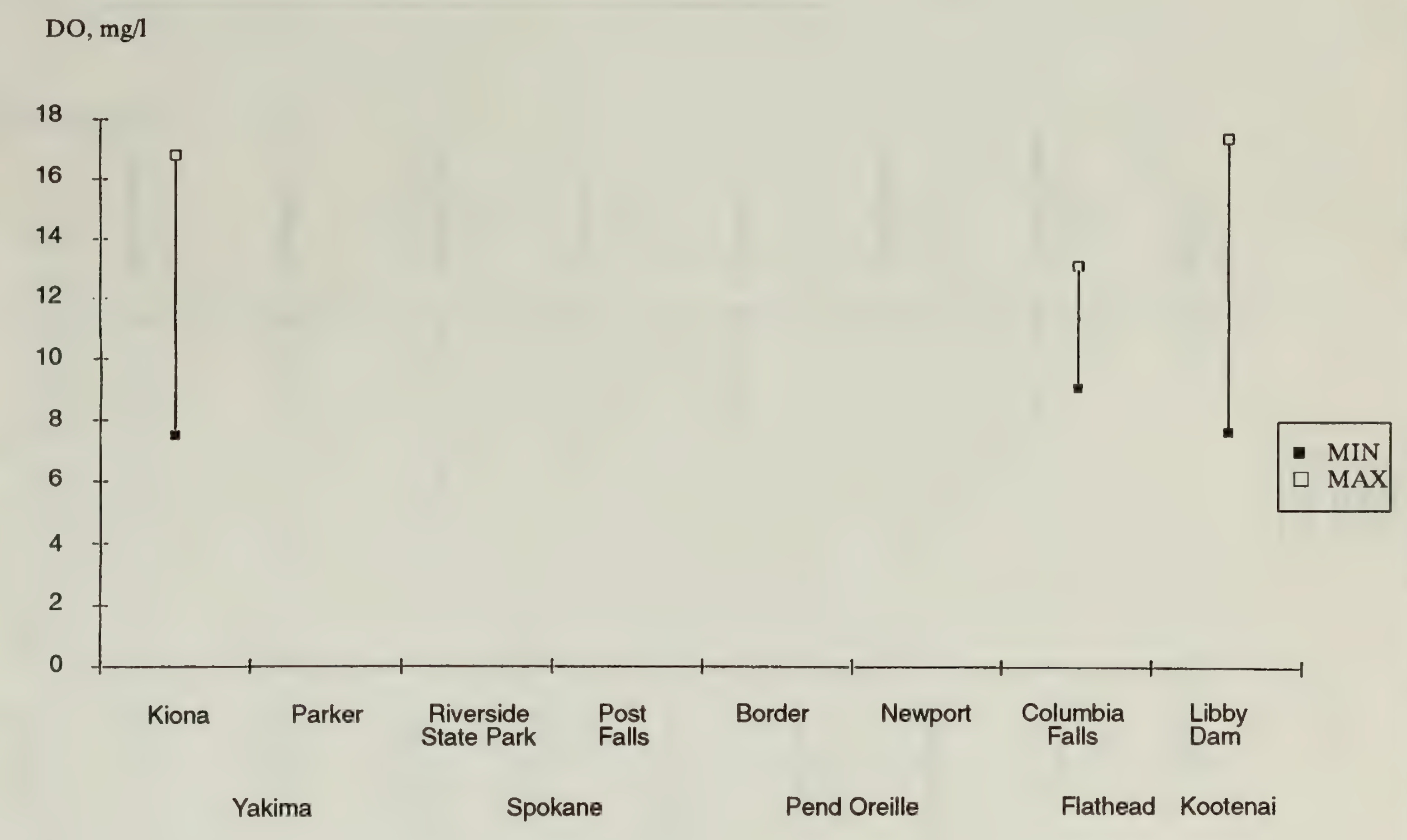


Figure B–17. Tributaries DO (mg/l)

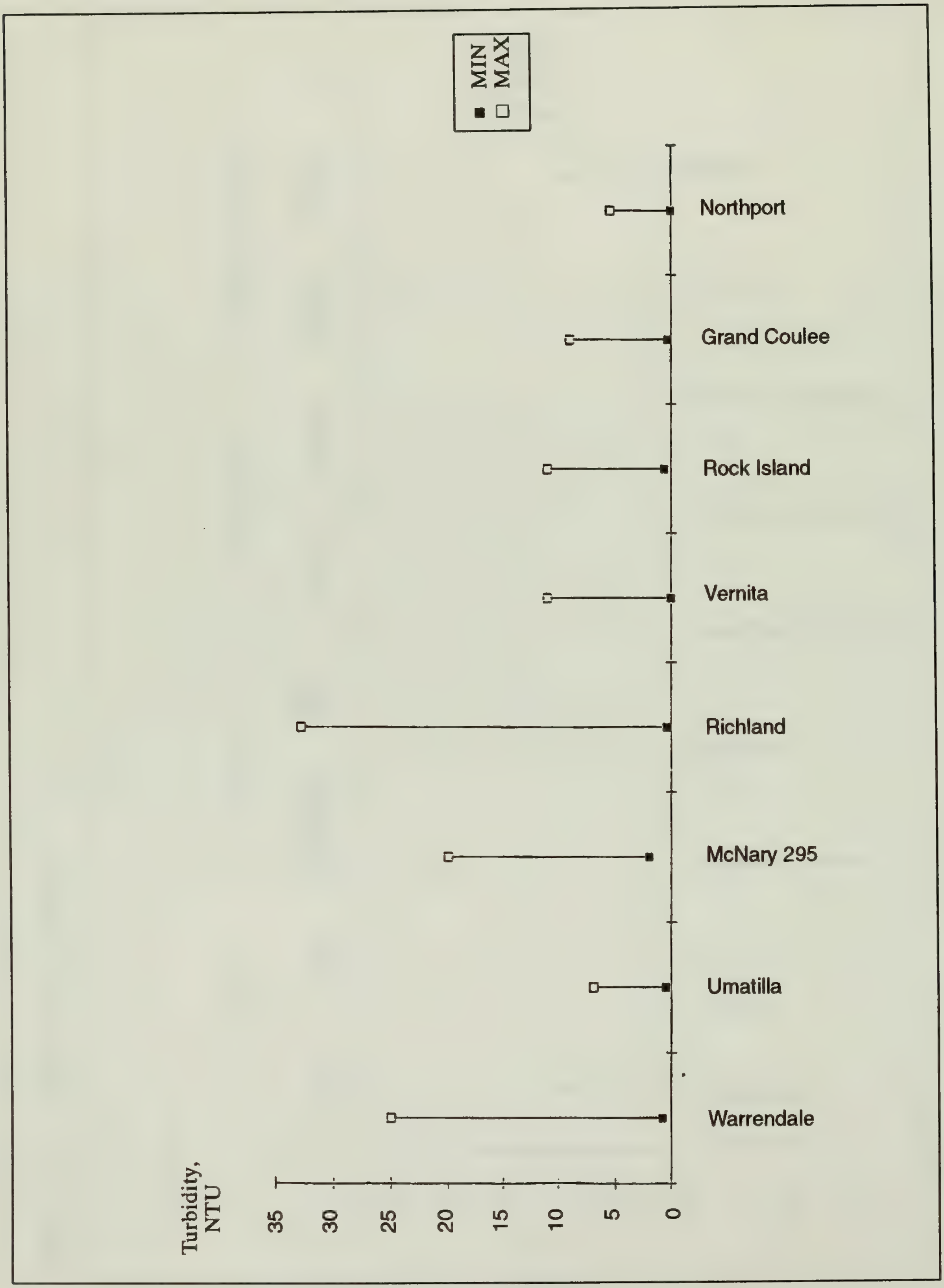


**Figure B–18. Columbia River Turbidity (NTU)**

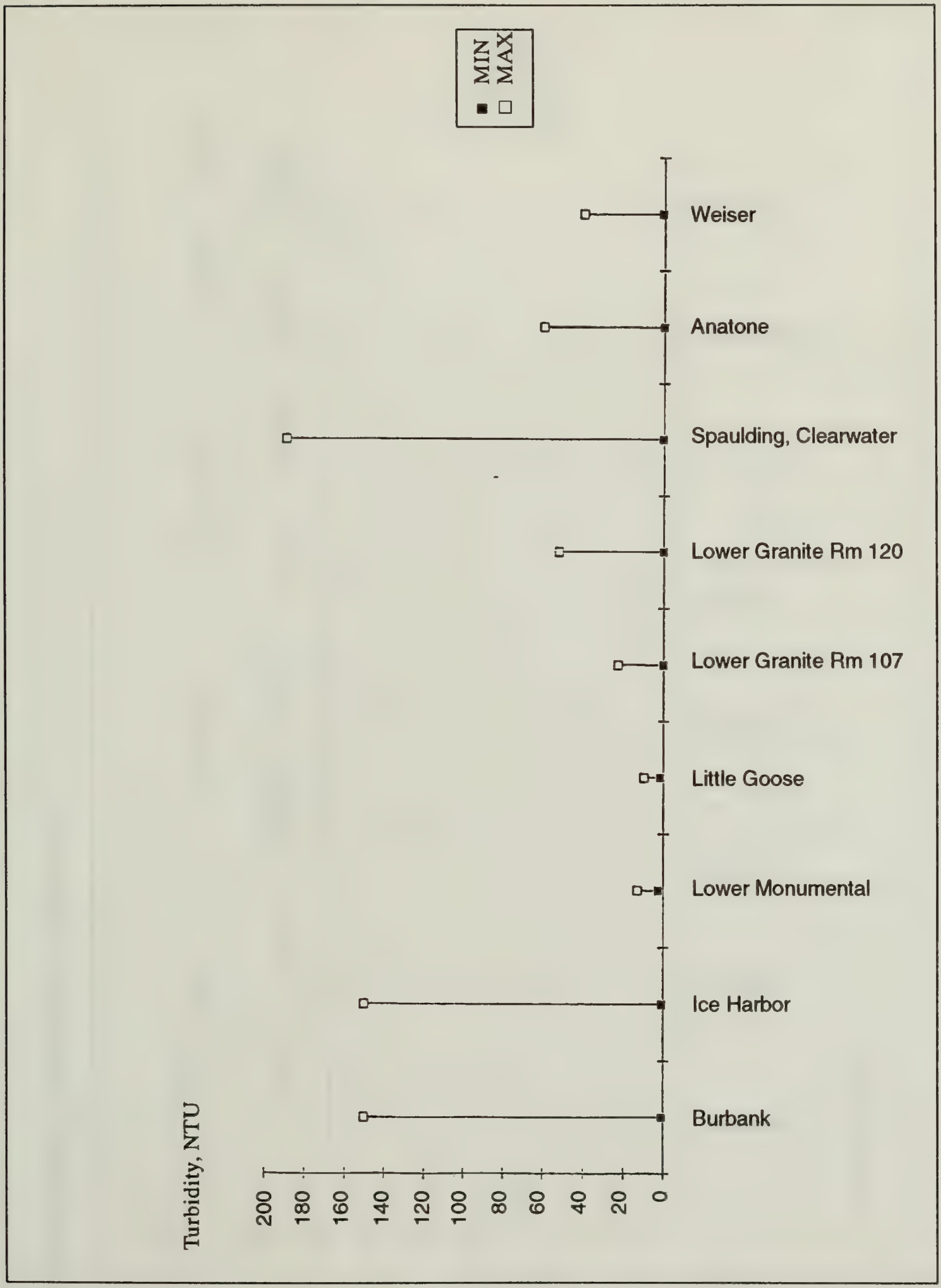


**Figure B–19. Snake River & Clearwater Turbitity (NTU)**

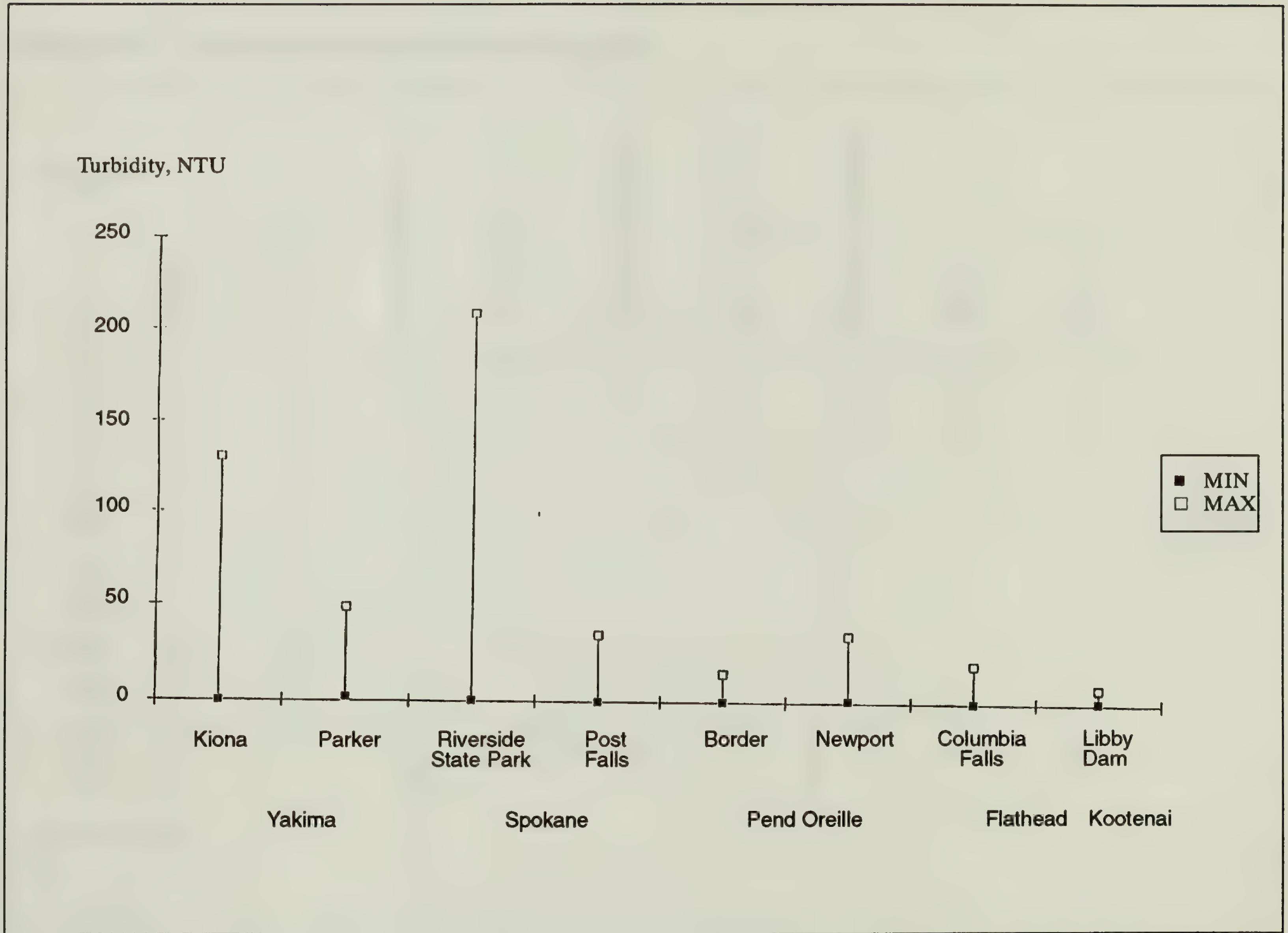


Figure B–20. Tributaries Turbitity (NTU)

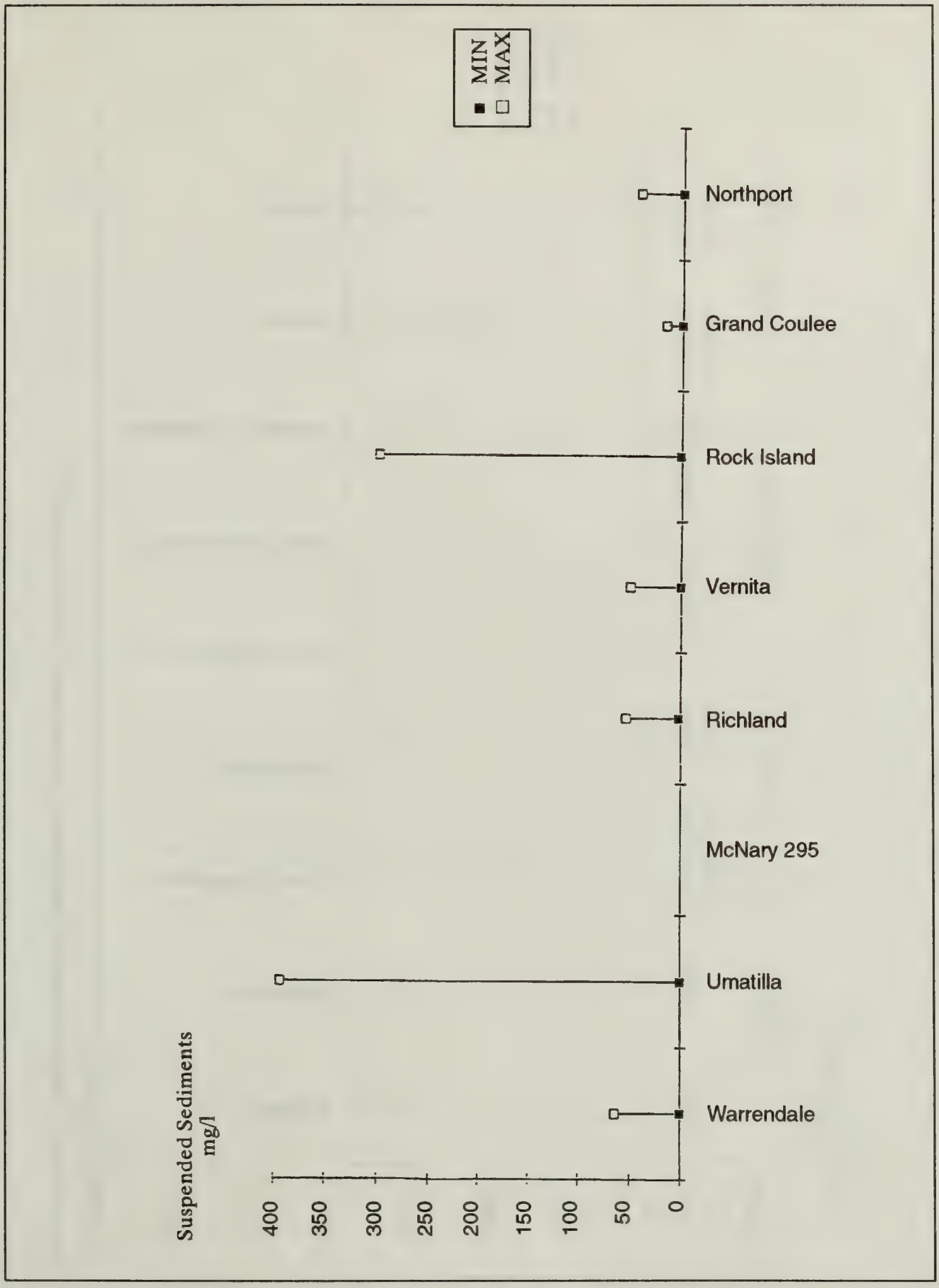


**Figure B–21. Columbia River Suspended Sediment (mg/l)**

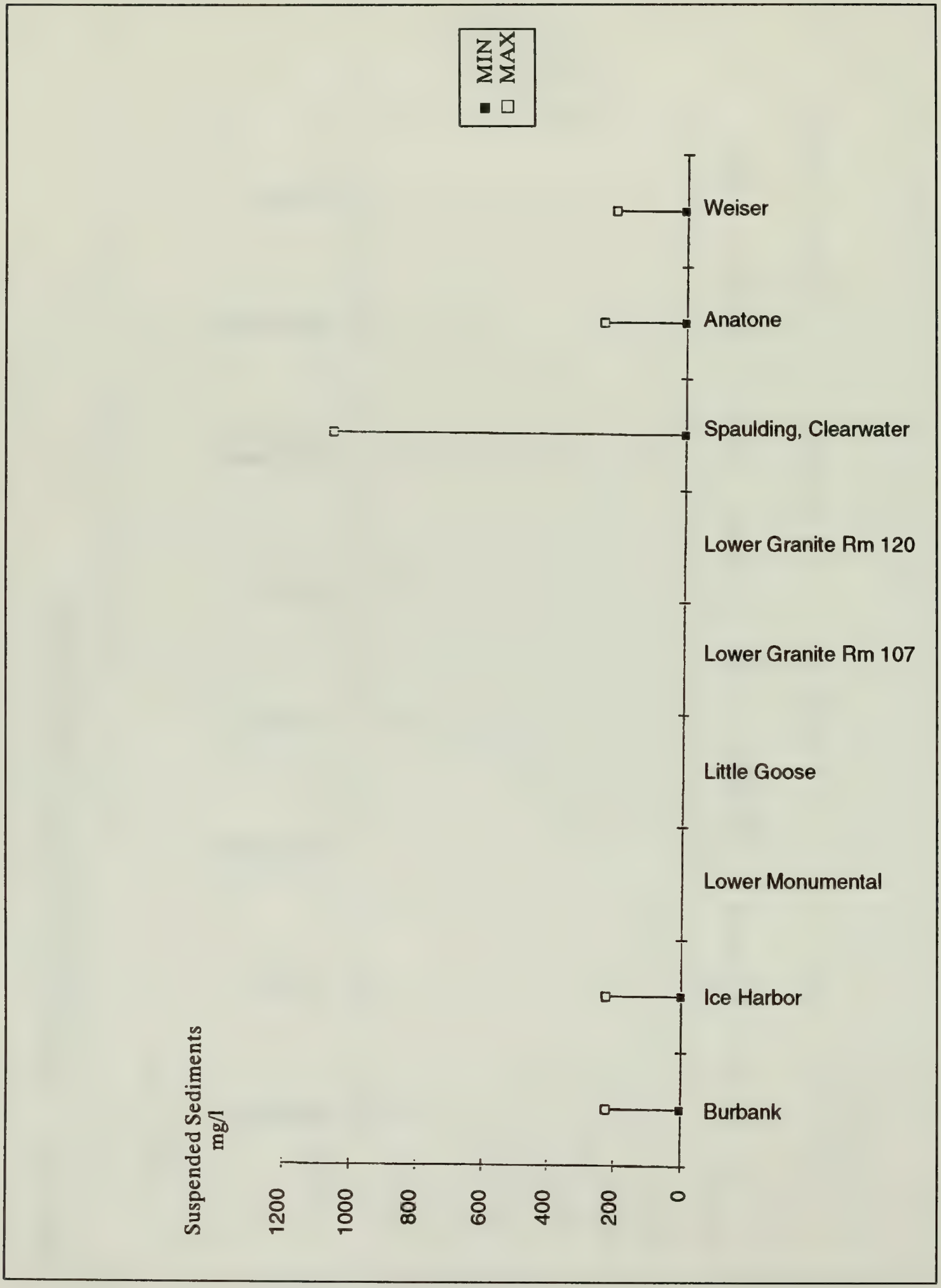


**Figure B–22. Snake River & Clearwater, Suspended Sediment (mg/l)**

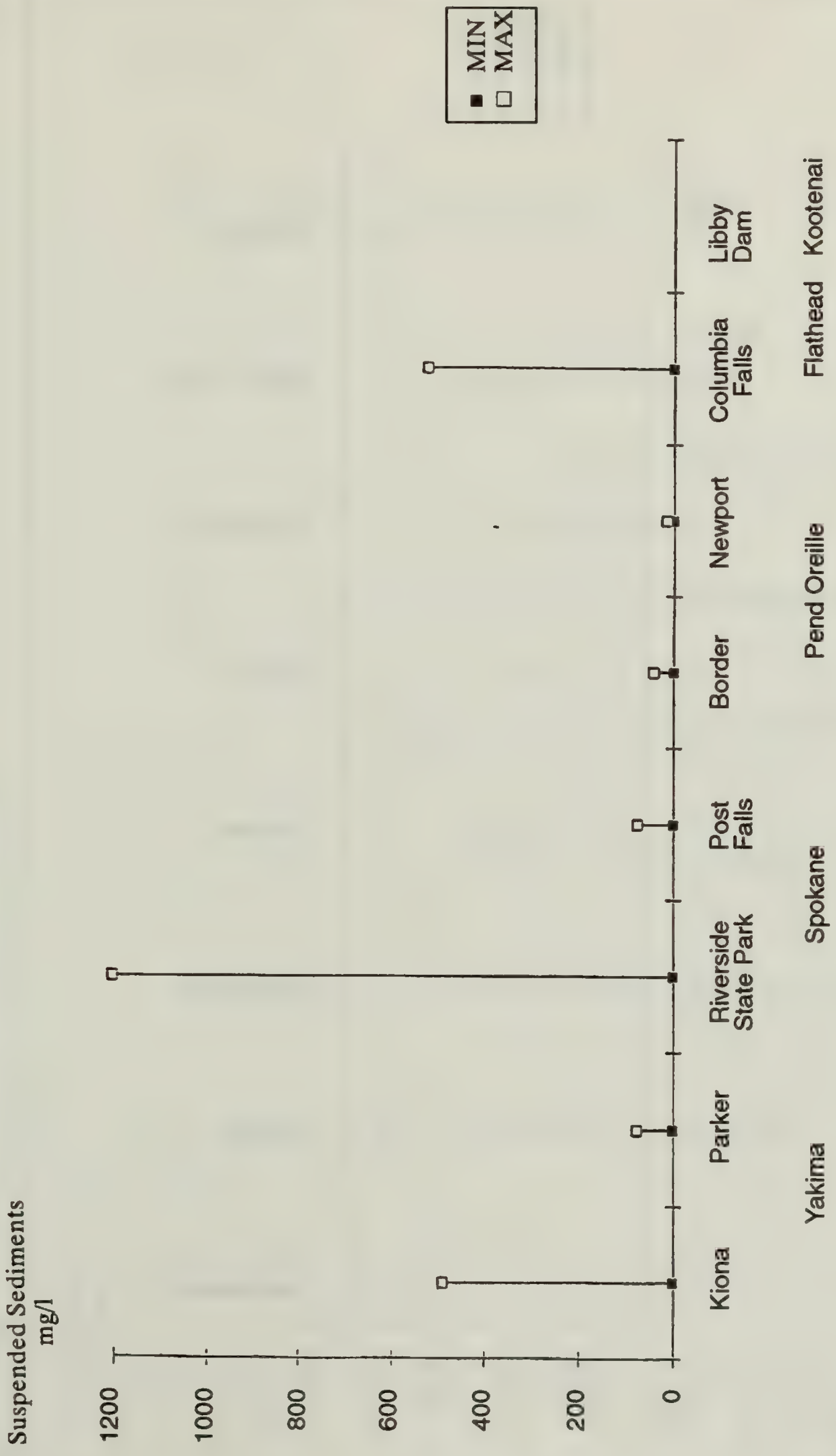


Figure B–23. Tributaries Suspended Sediment (mg/l)

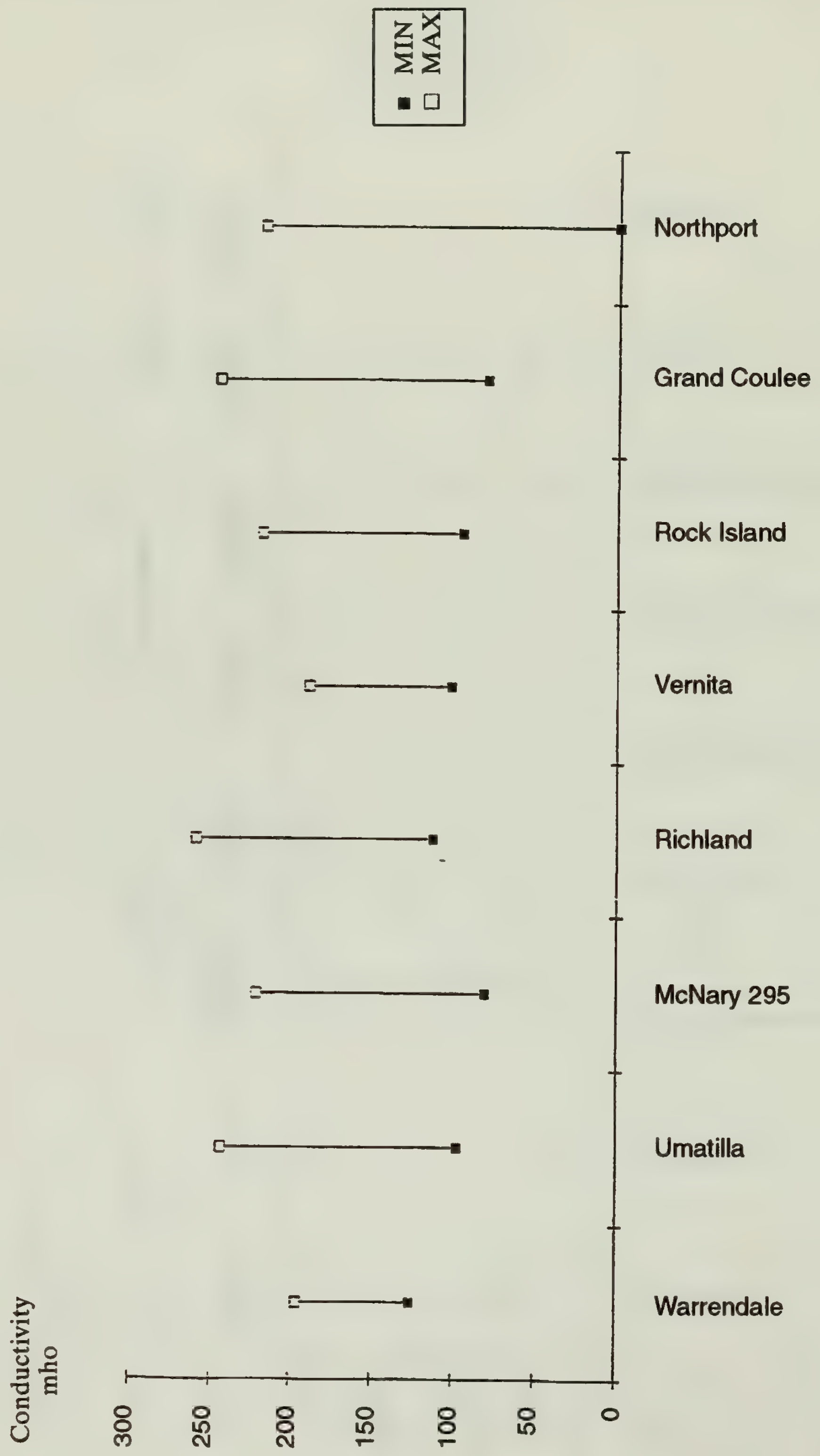


**Figure B–24.** Columbia River Conductivity (mho)

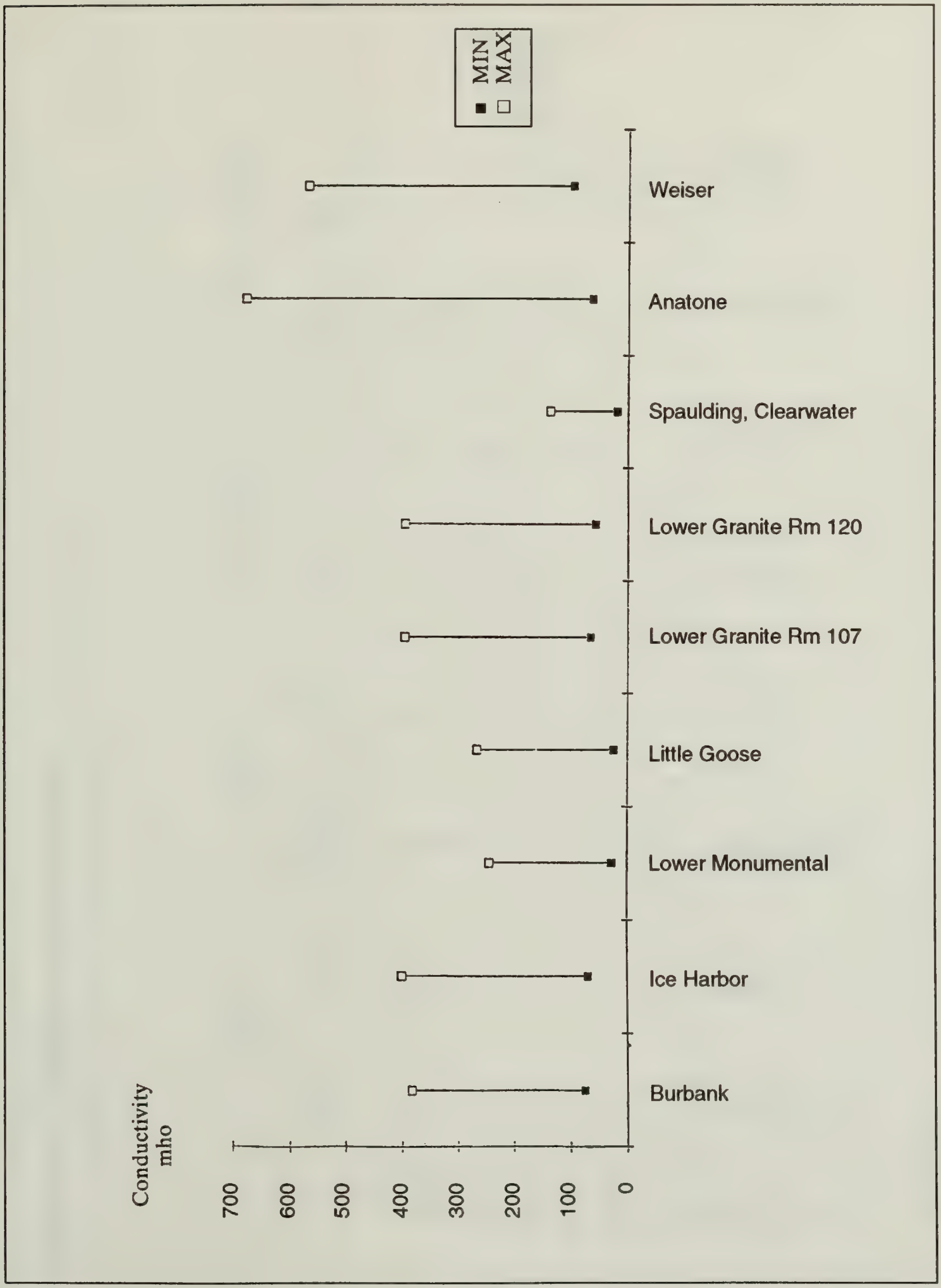


**Figure B–25. Snake River & Clearwater, Conductivity (mho)**

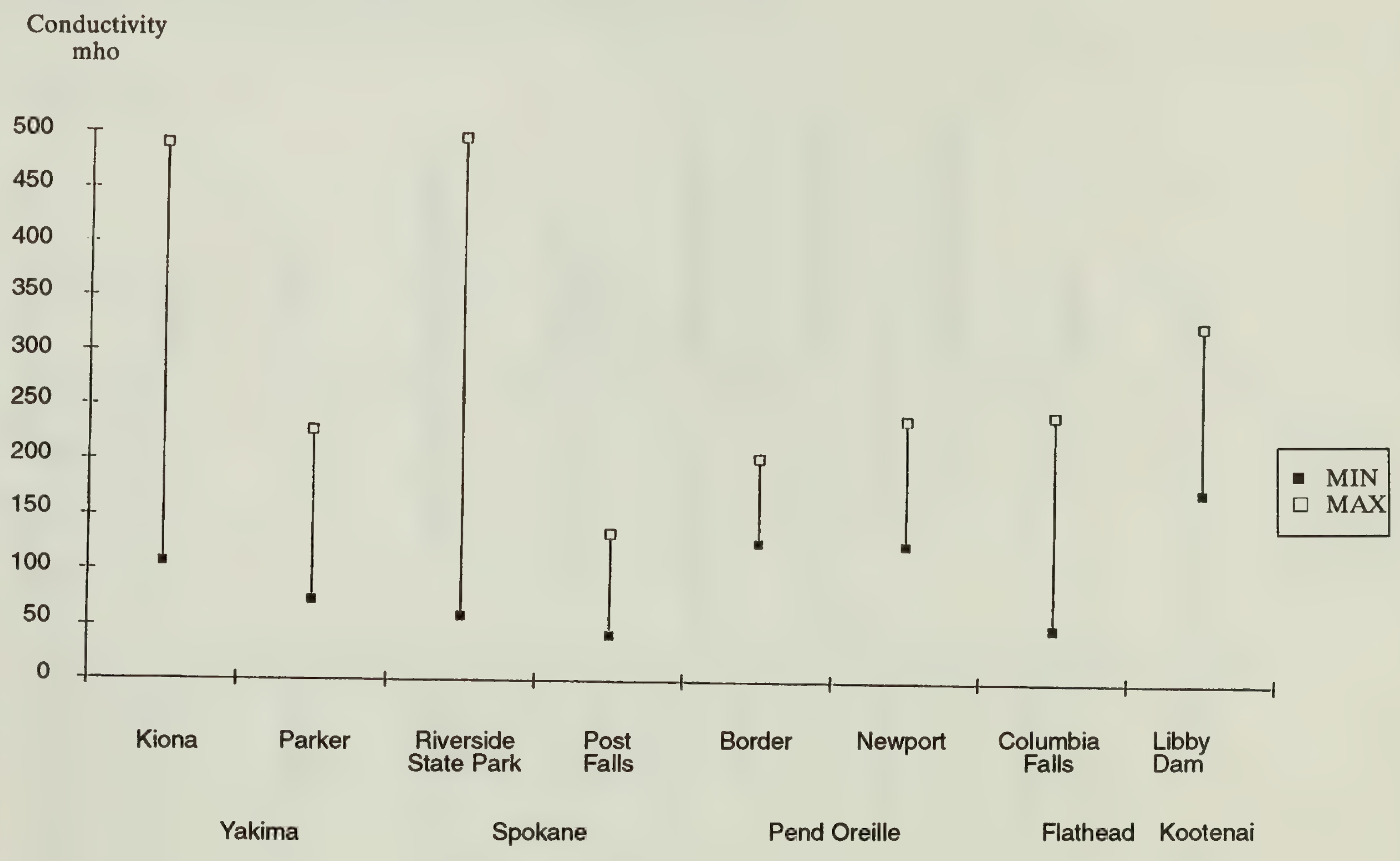


**Figure B–26. Tributaries Conductivity (mho)**

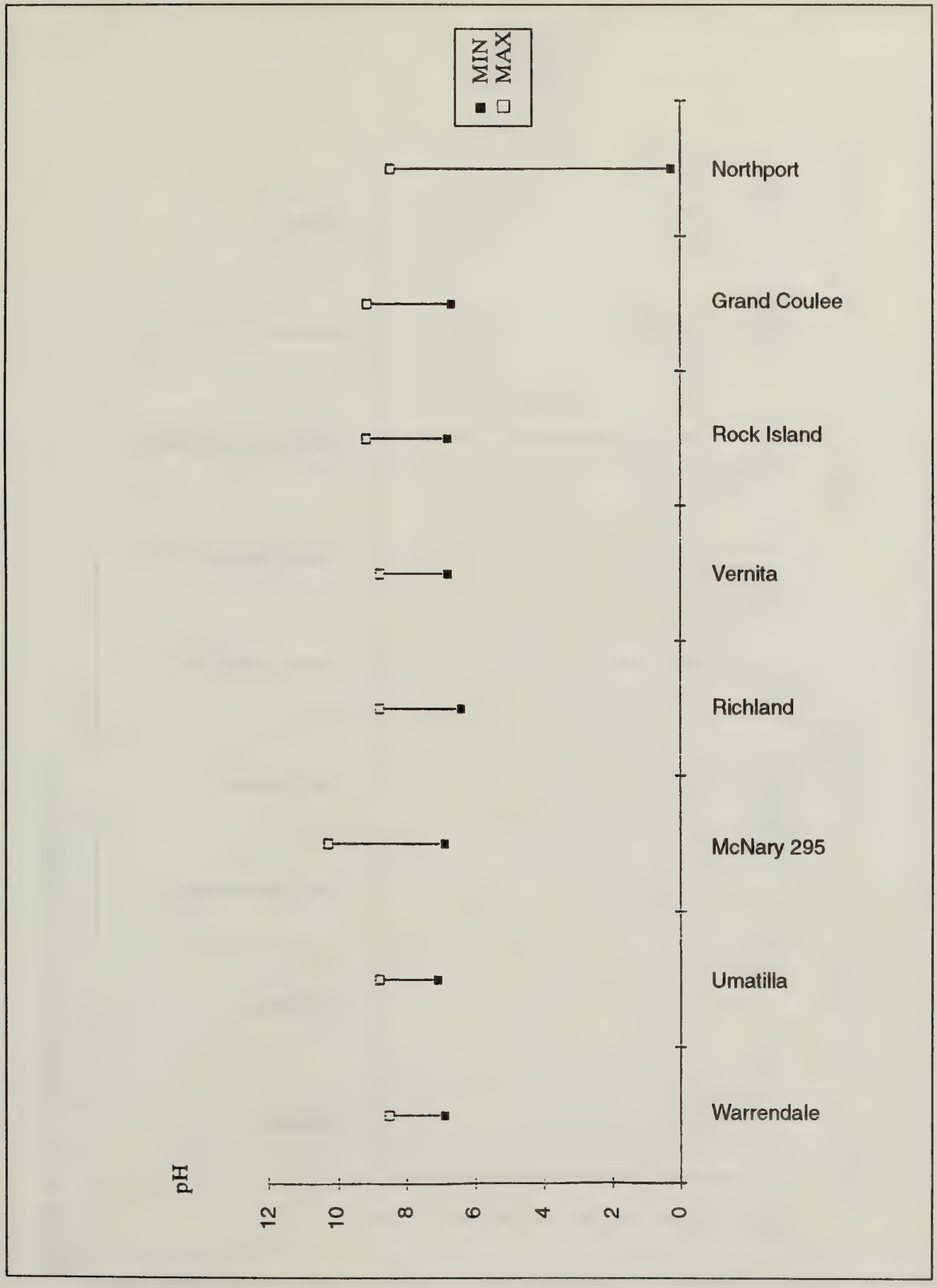


**Figure B–27. Columbia River pH**

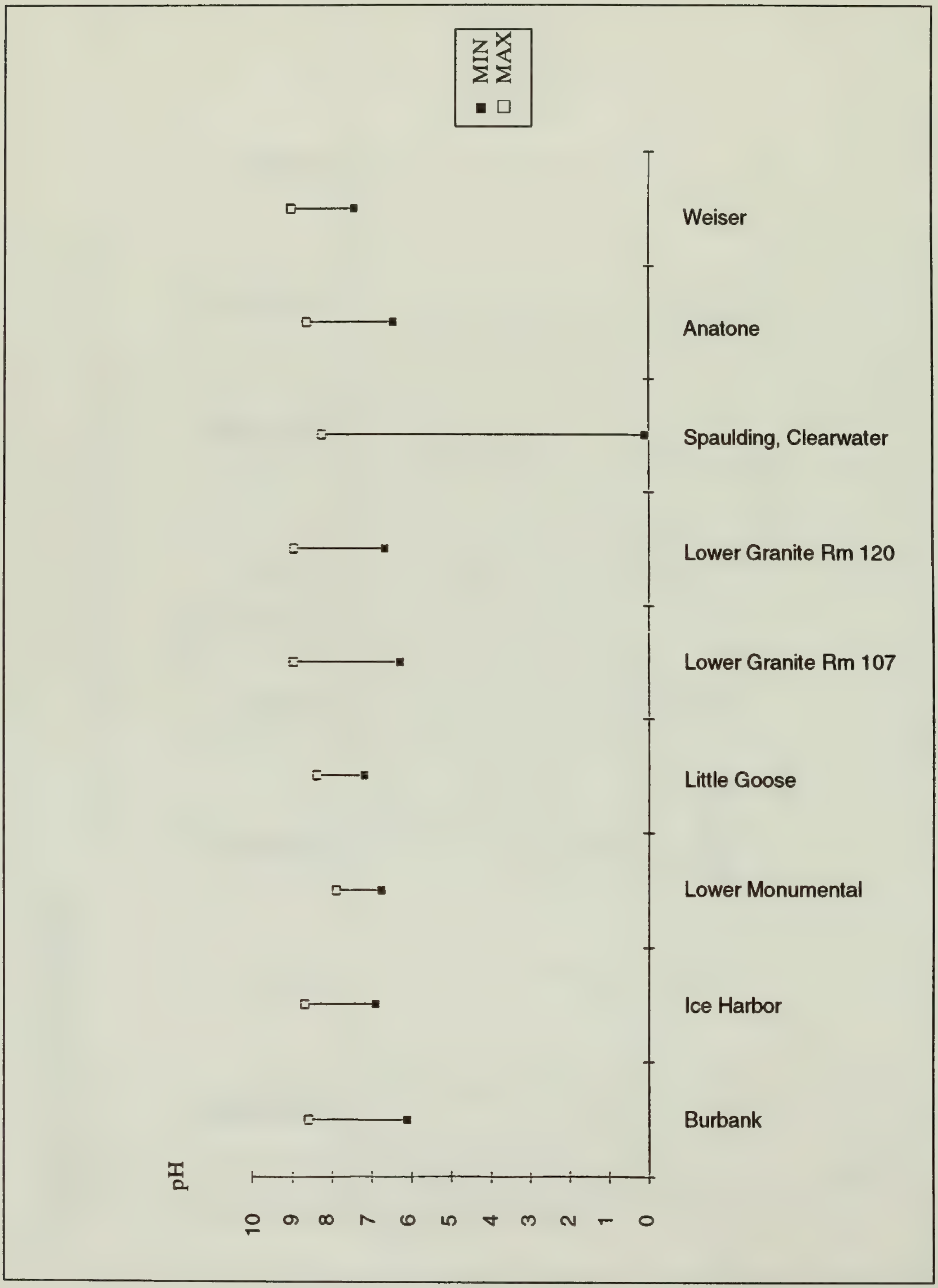


**Figure B–28.** Snake River & Clearwater pH

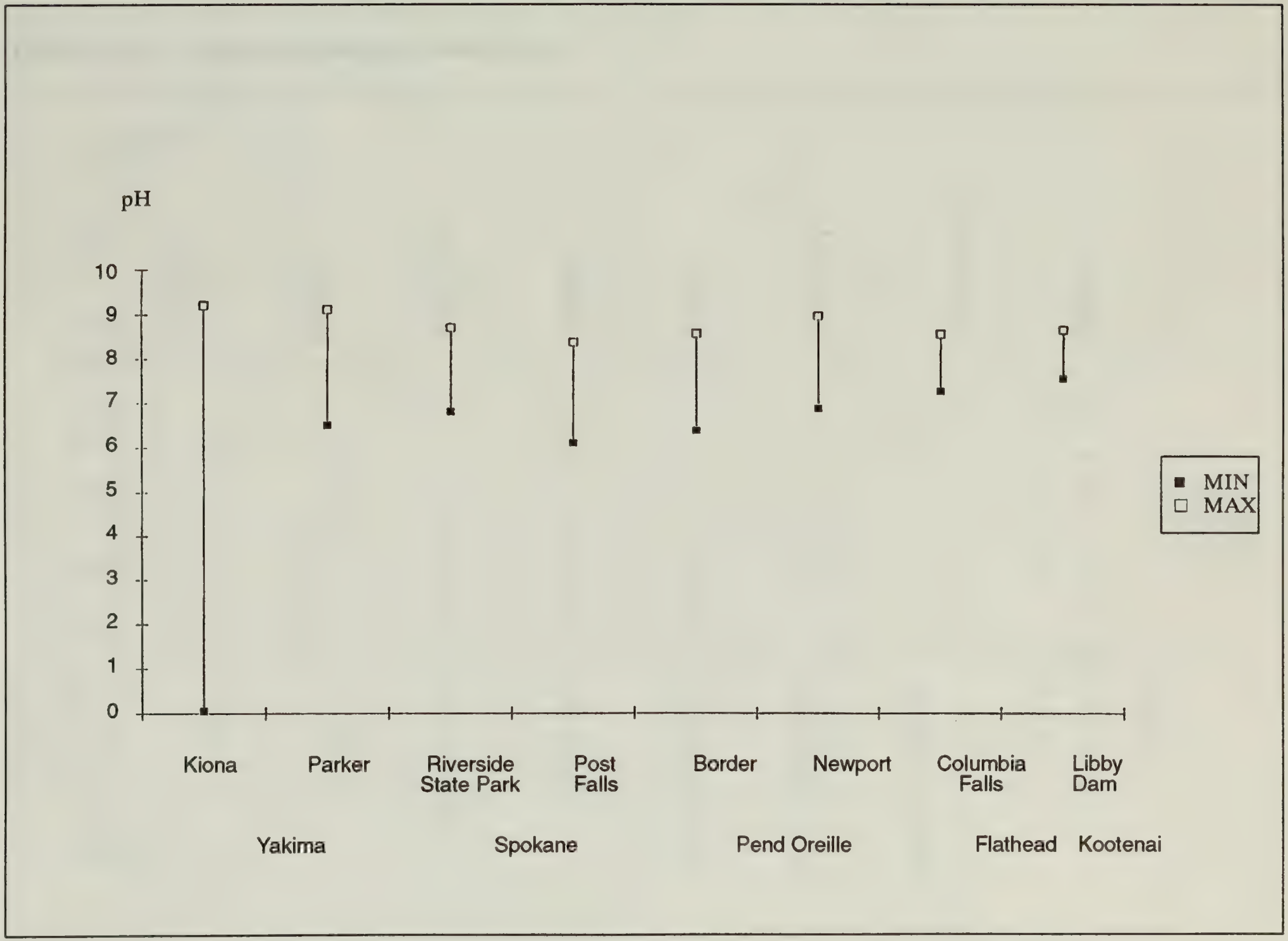


Figure B–29. Tributaries pH

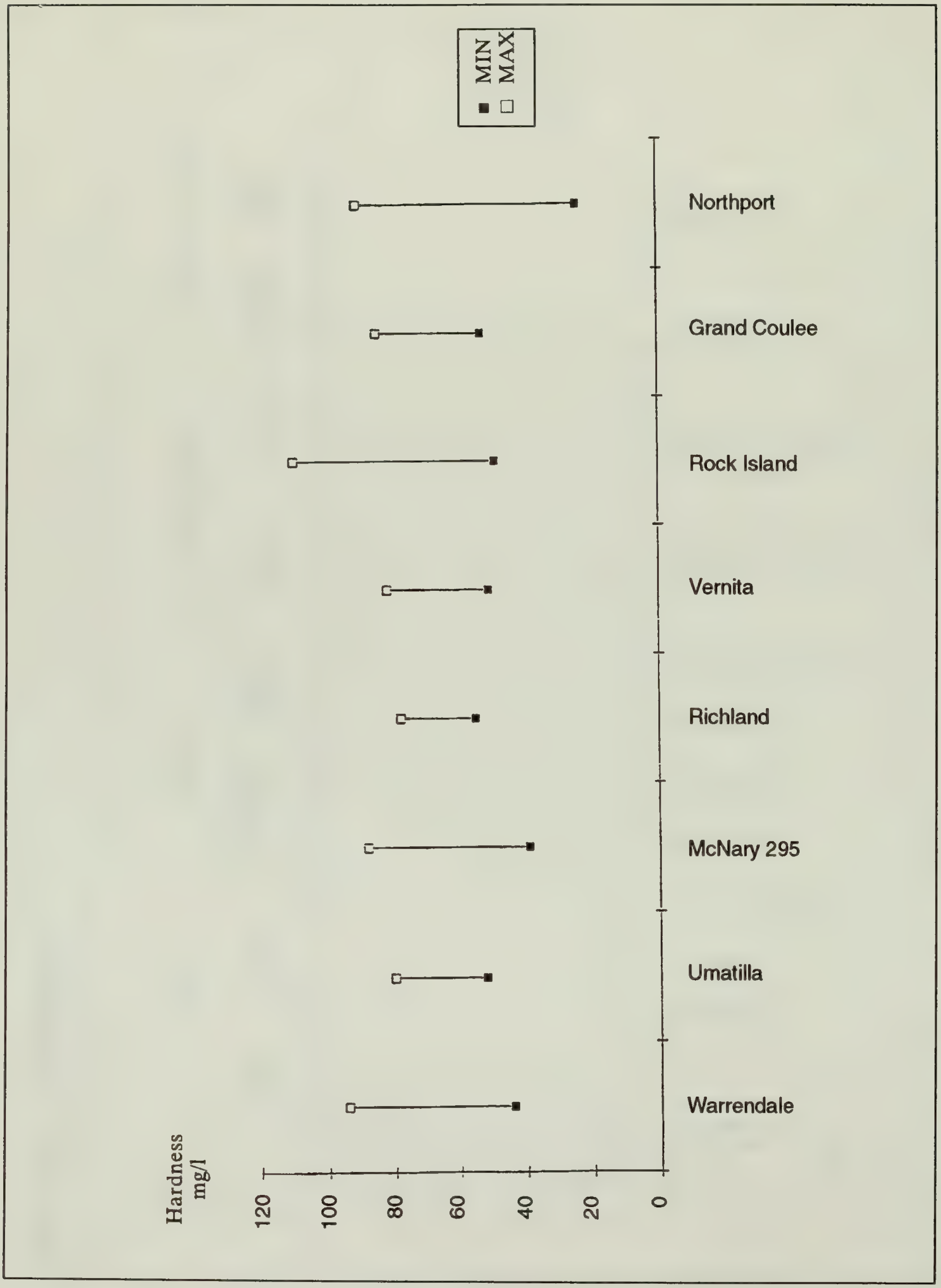


Figure B–30. Columbia River Hardness (mg/l)

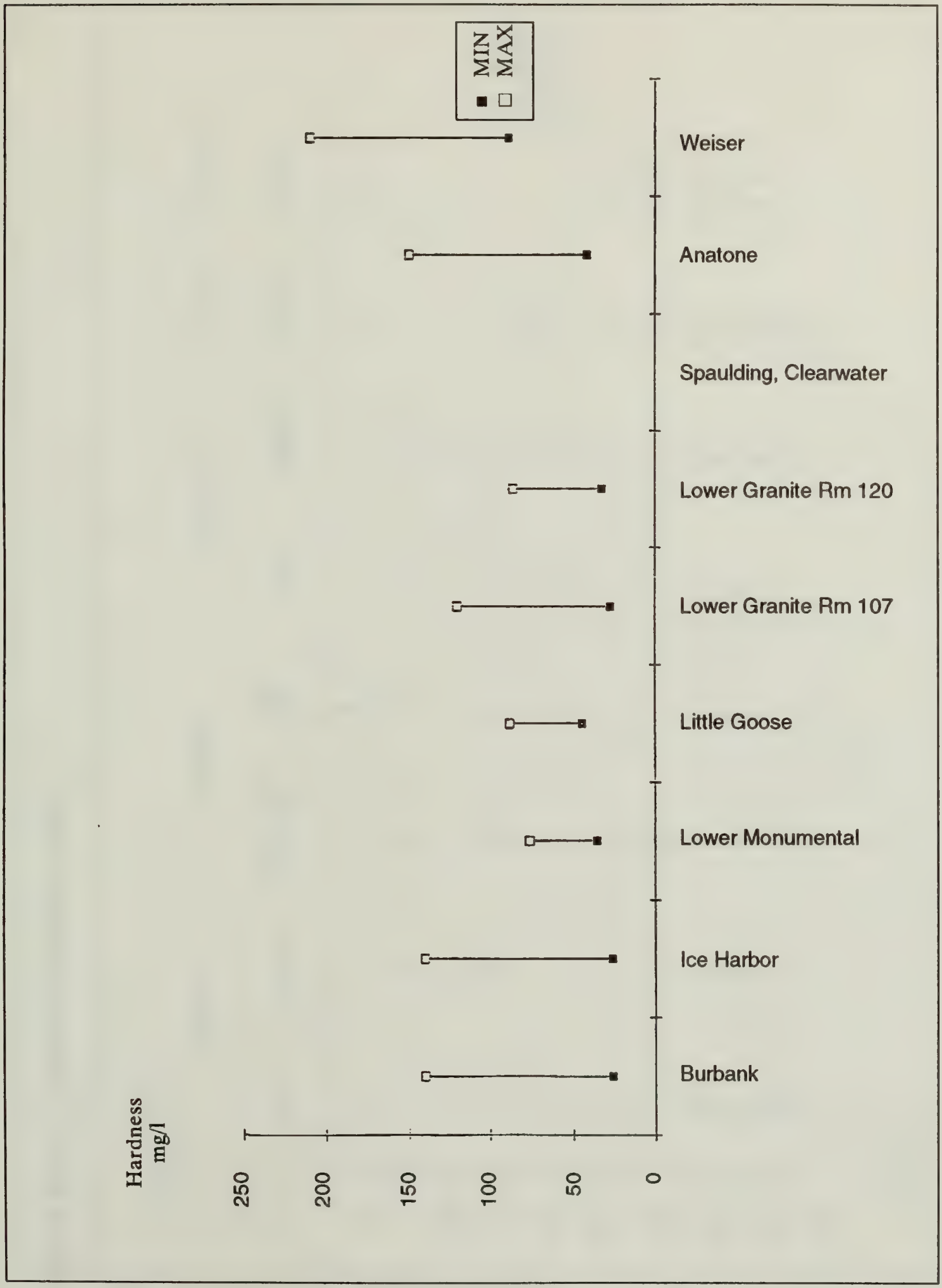


**Figure B–31.** Snake River & Clearwater Hardness (mg/l)

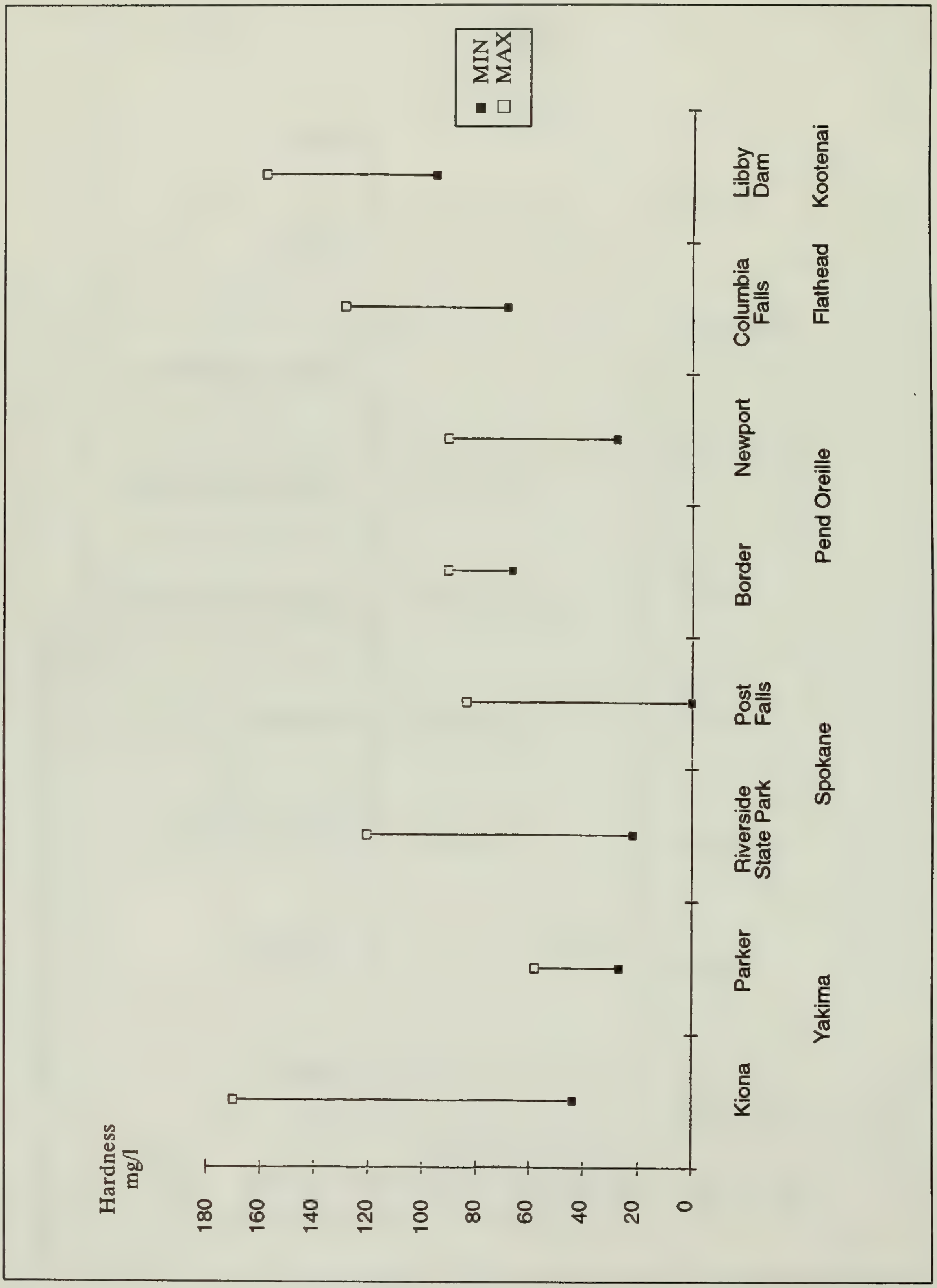


**Figure B–32.** Tributaries Hardness (mg/l)

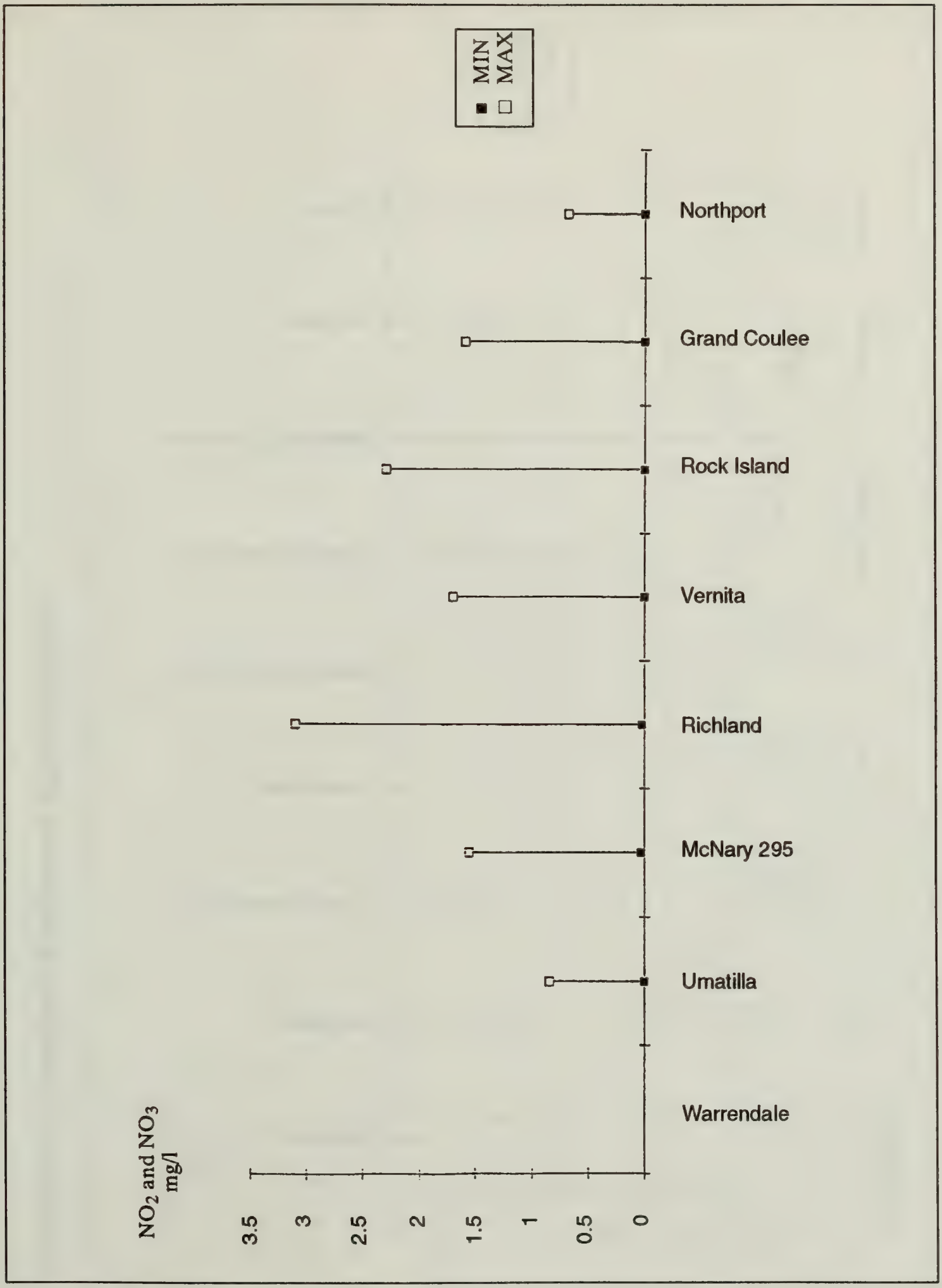


**Figure B–33.** Columbia River NO2 & NO3 (mg/l)

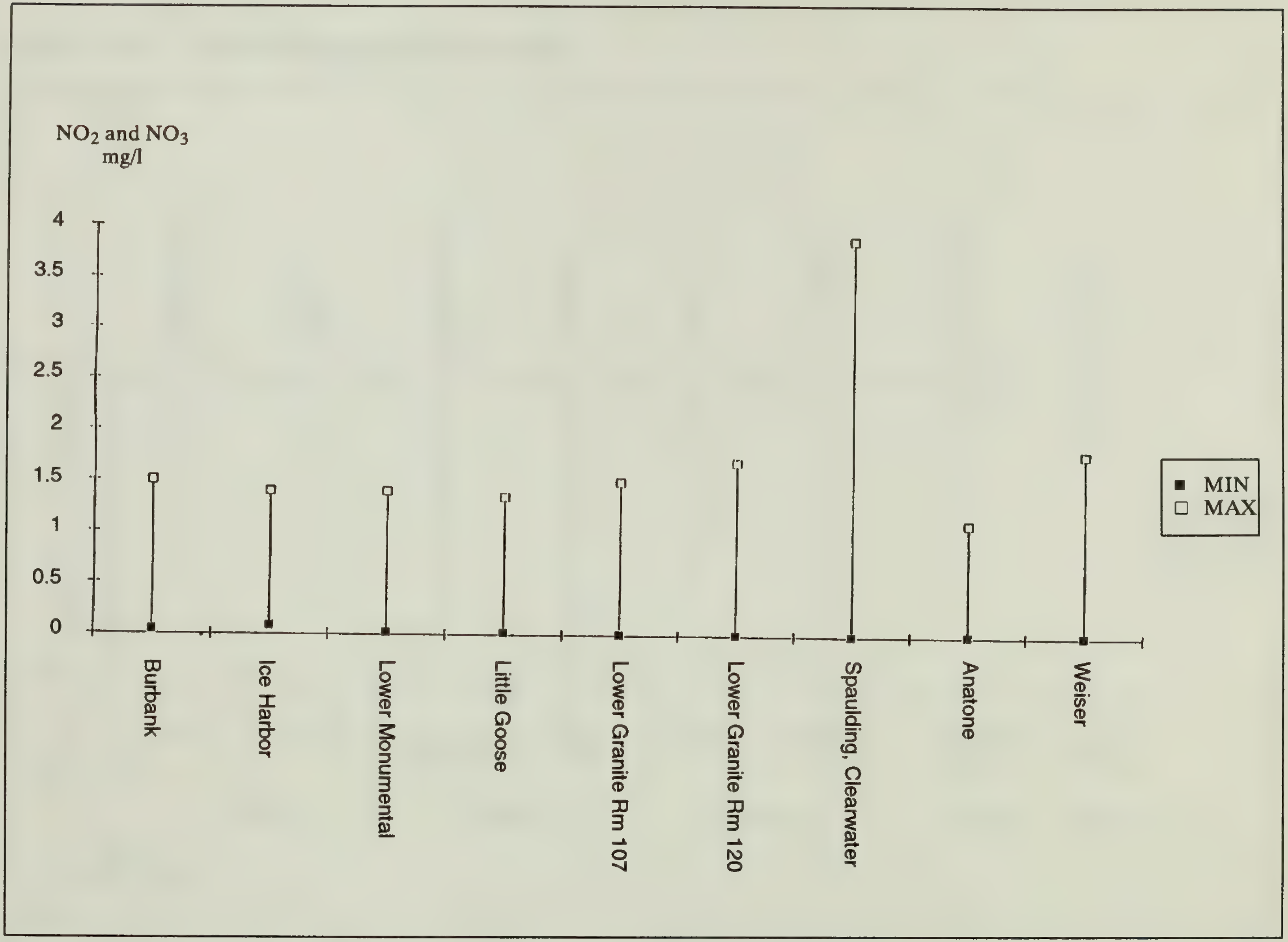


Figure B–34. Snake River & Clearwater NO2 & NO3 (mg/l)

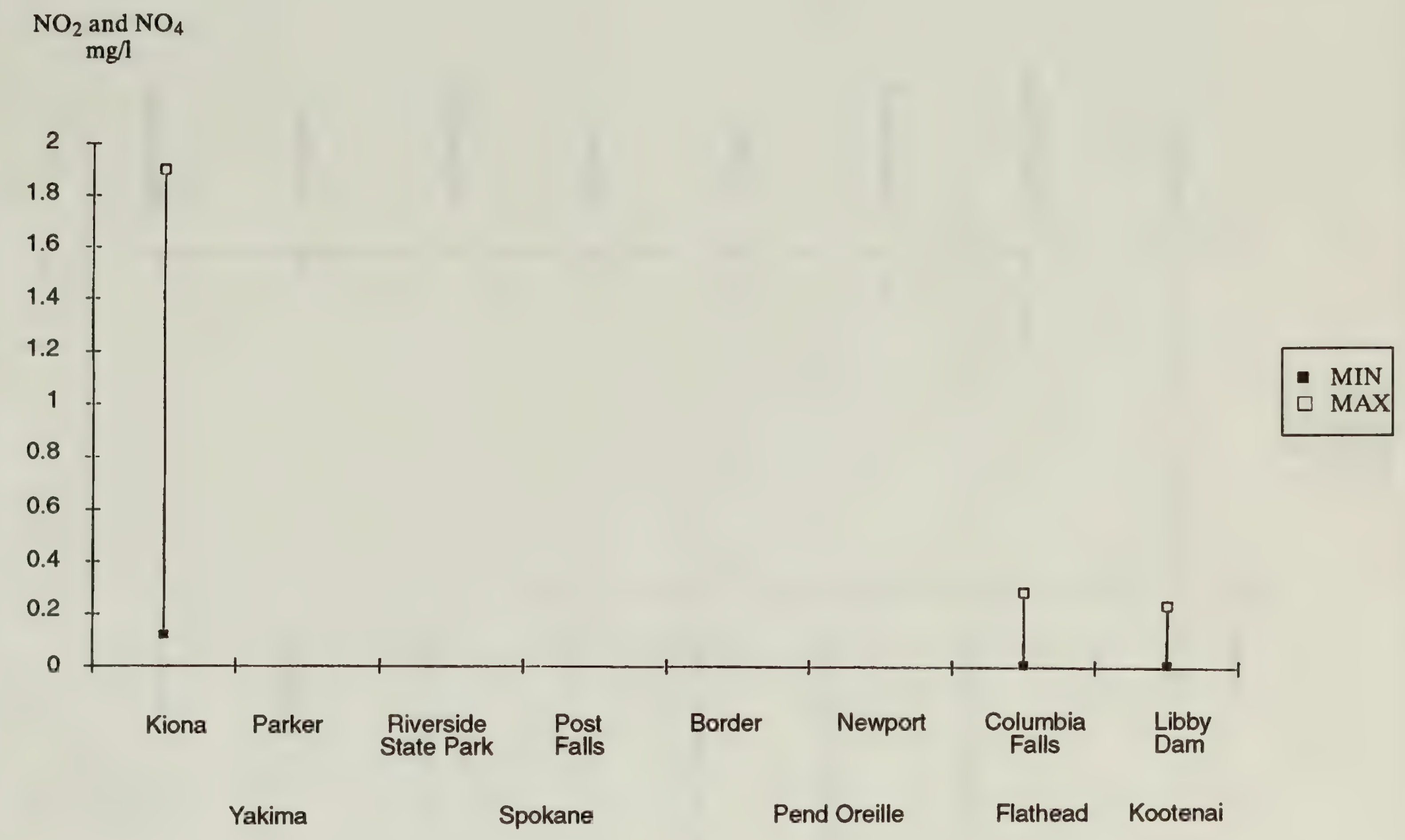


**Figure B–35.** **Tributaries NO2 & NO# (mg/l)**

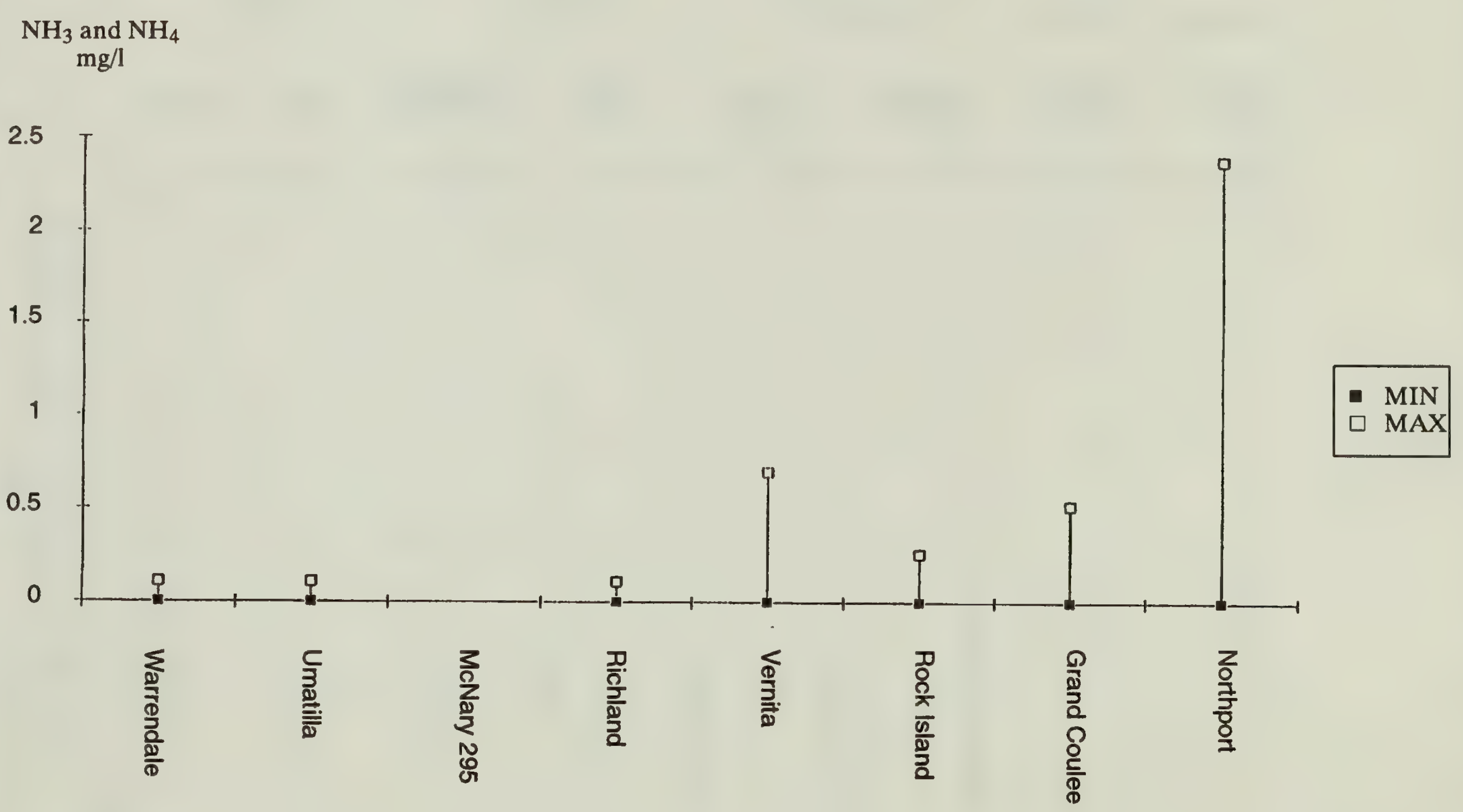


Figure B–36. **Columbia River NH3 & NH4 (mg/l)**

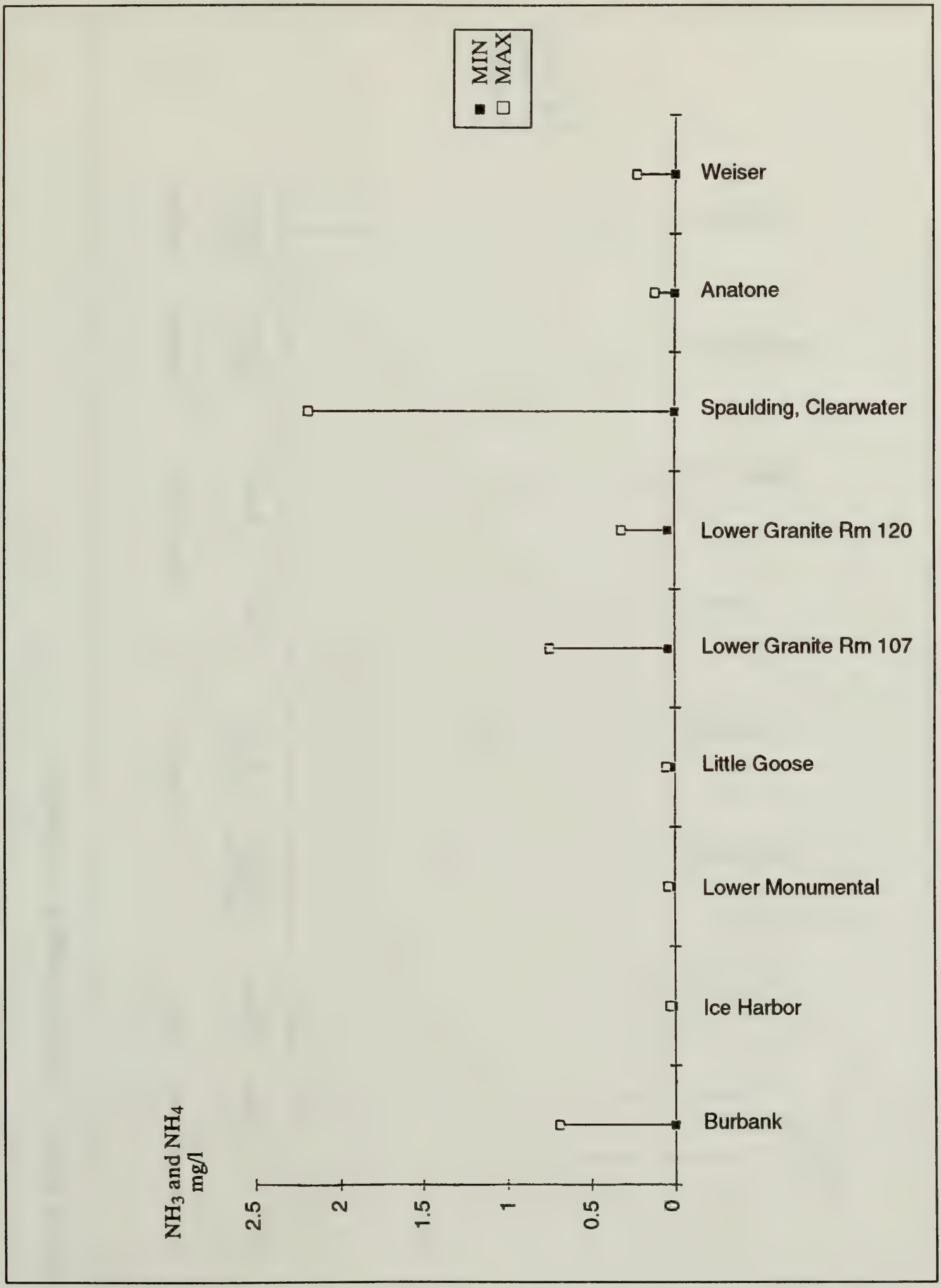


**Figure B–37.** Snake River & Clearwater NH3 & NH4 (mg/l)

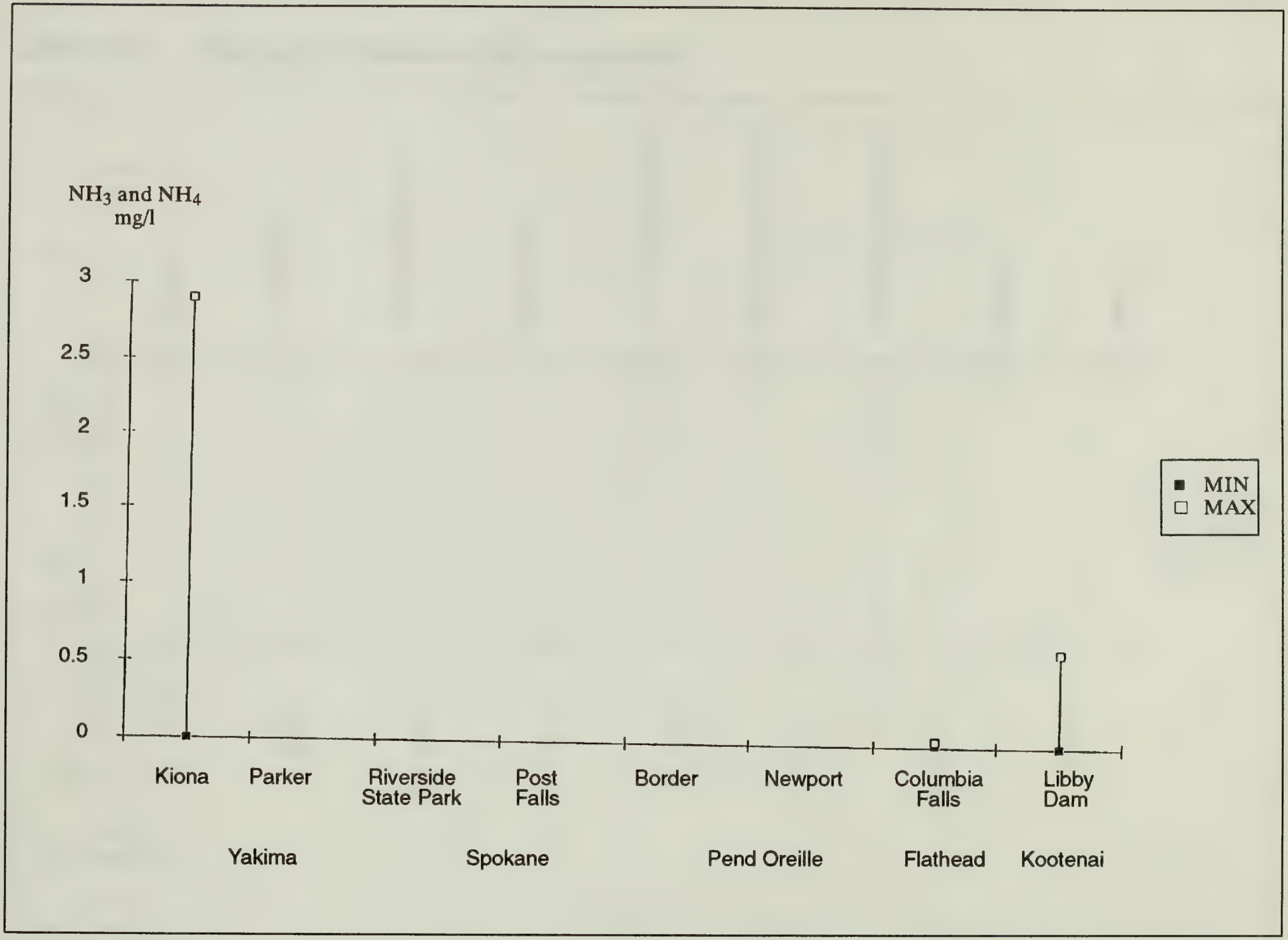


Figure B–38. Tributaries NH3 & NH4 (mg/l)

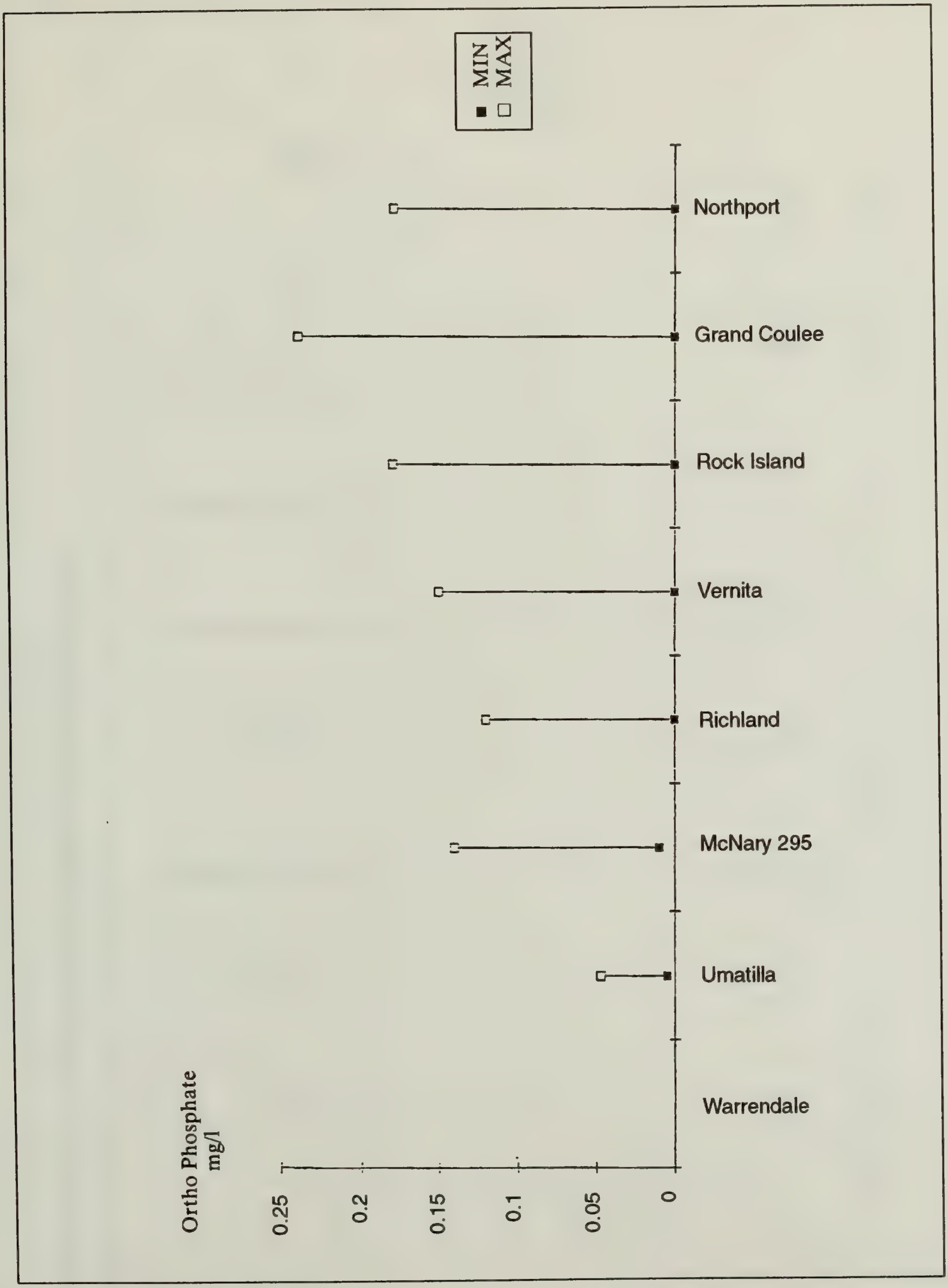


Figure B–39. Columbia River Ortho Phosphate (mg/l)

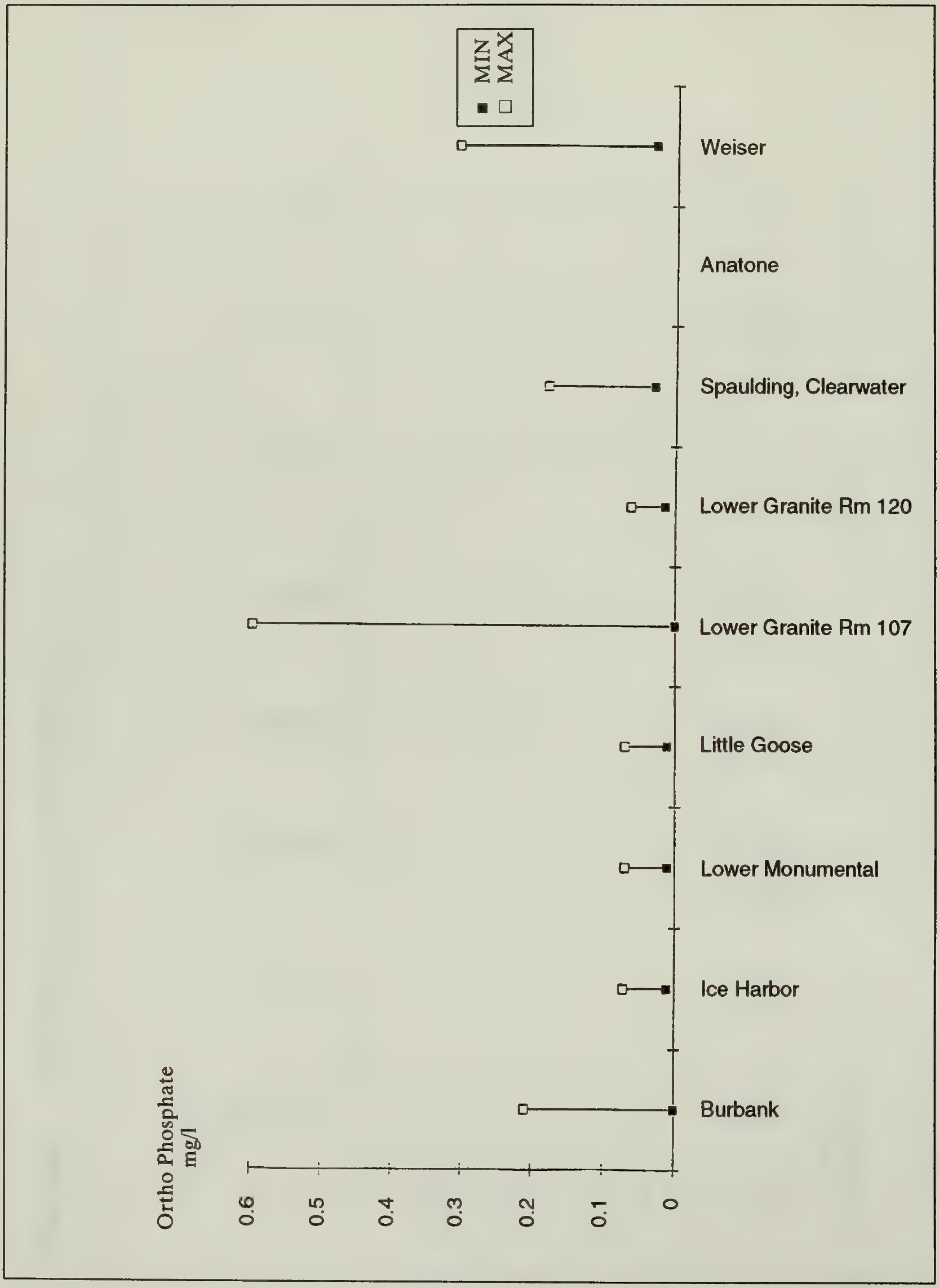


**Figure B–40.** **Snake River & Clearwater Ortho Phosphate (mg/l)**

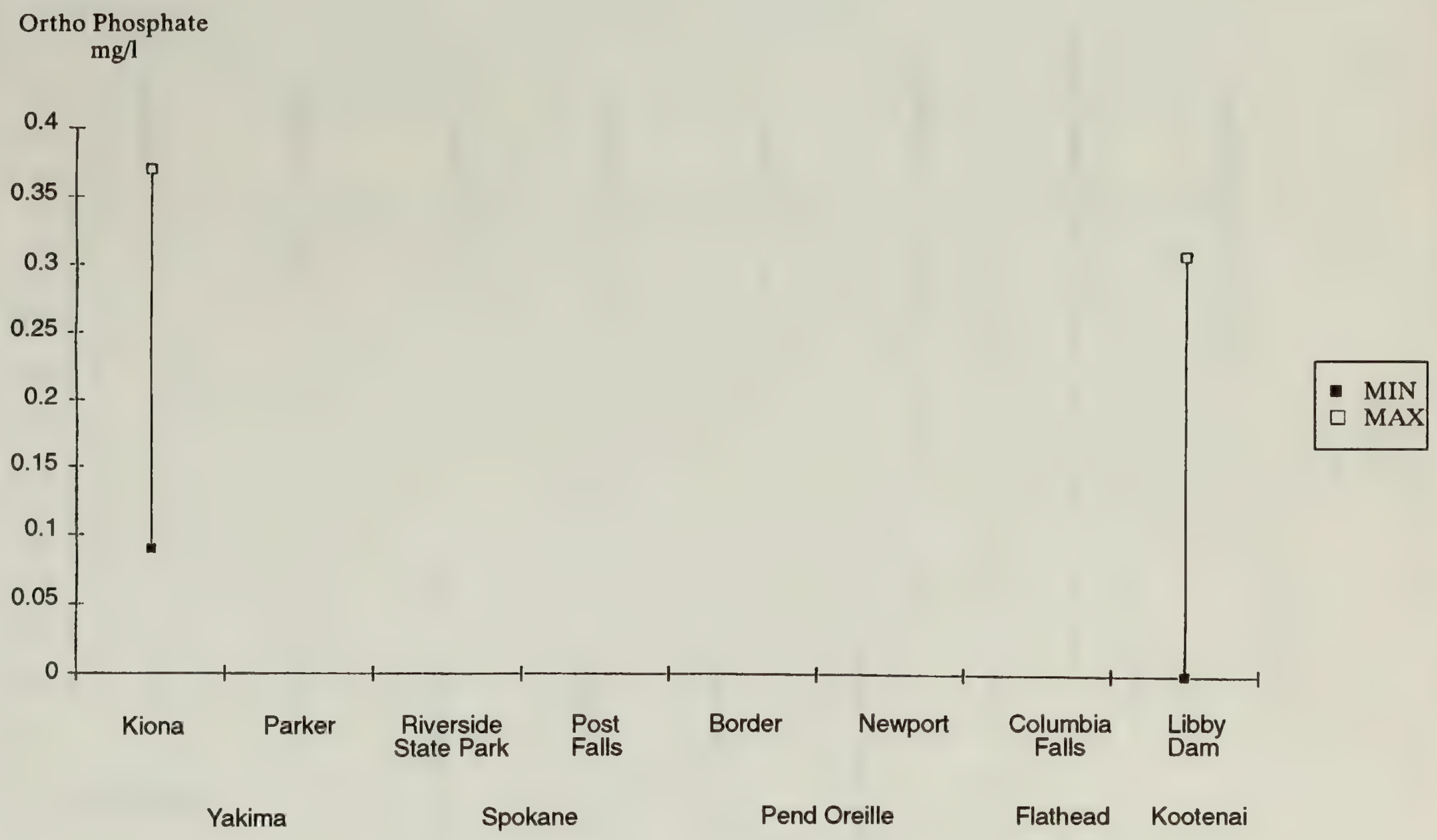


**Figure B–41. Tributaries Ortho Phosphate (mg/l)**

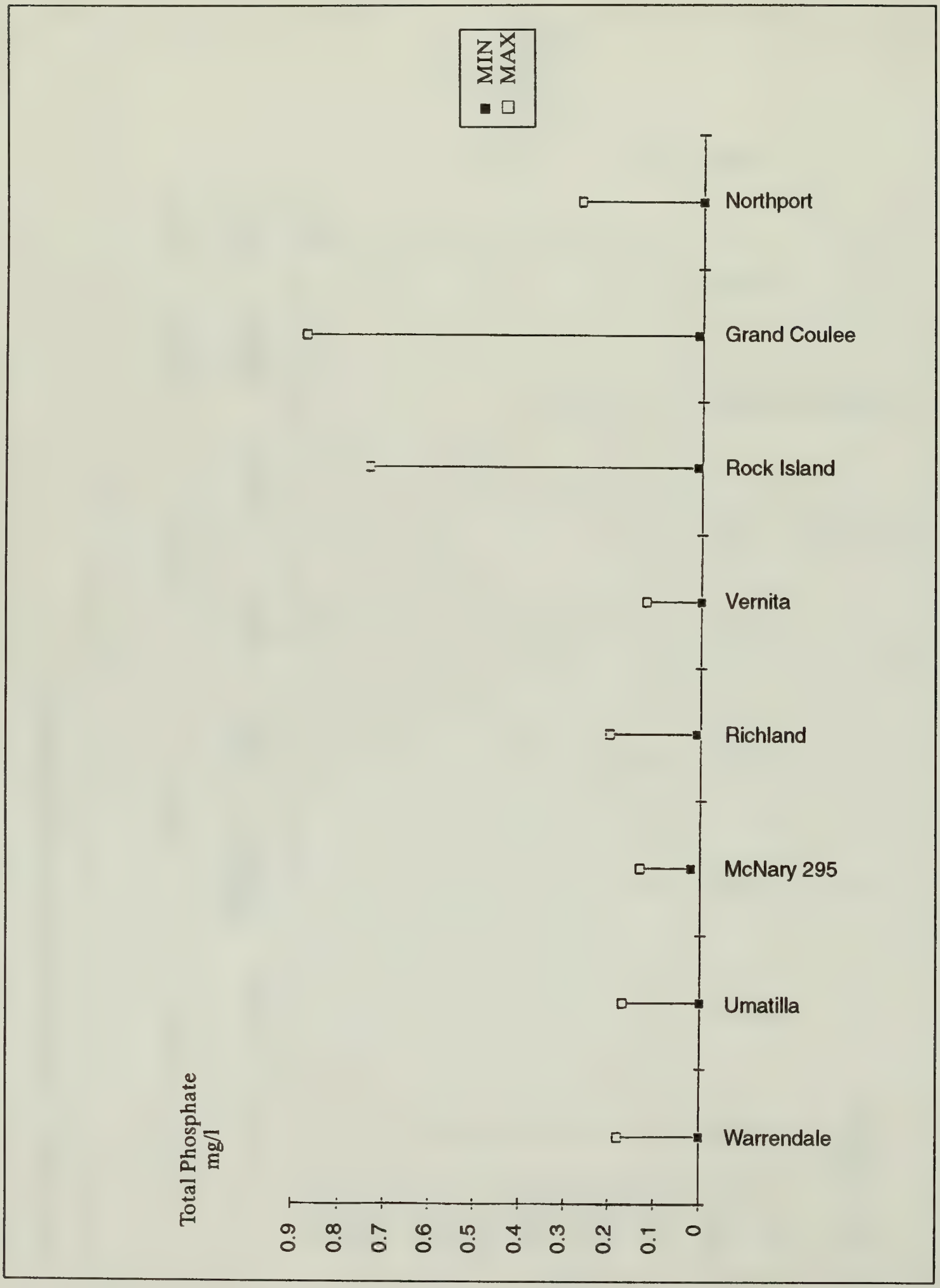


**Figure B–42. Columbia River Total Phosphate (mg/l)**

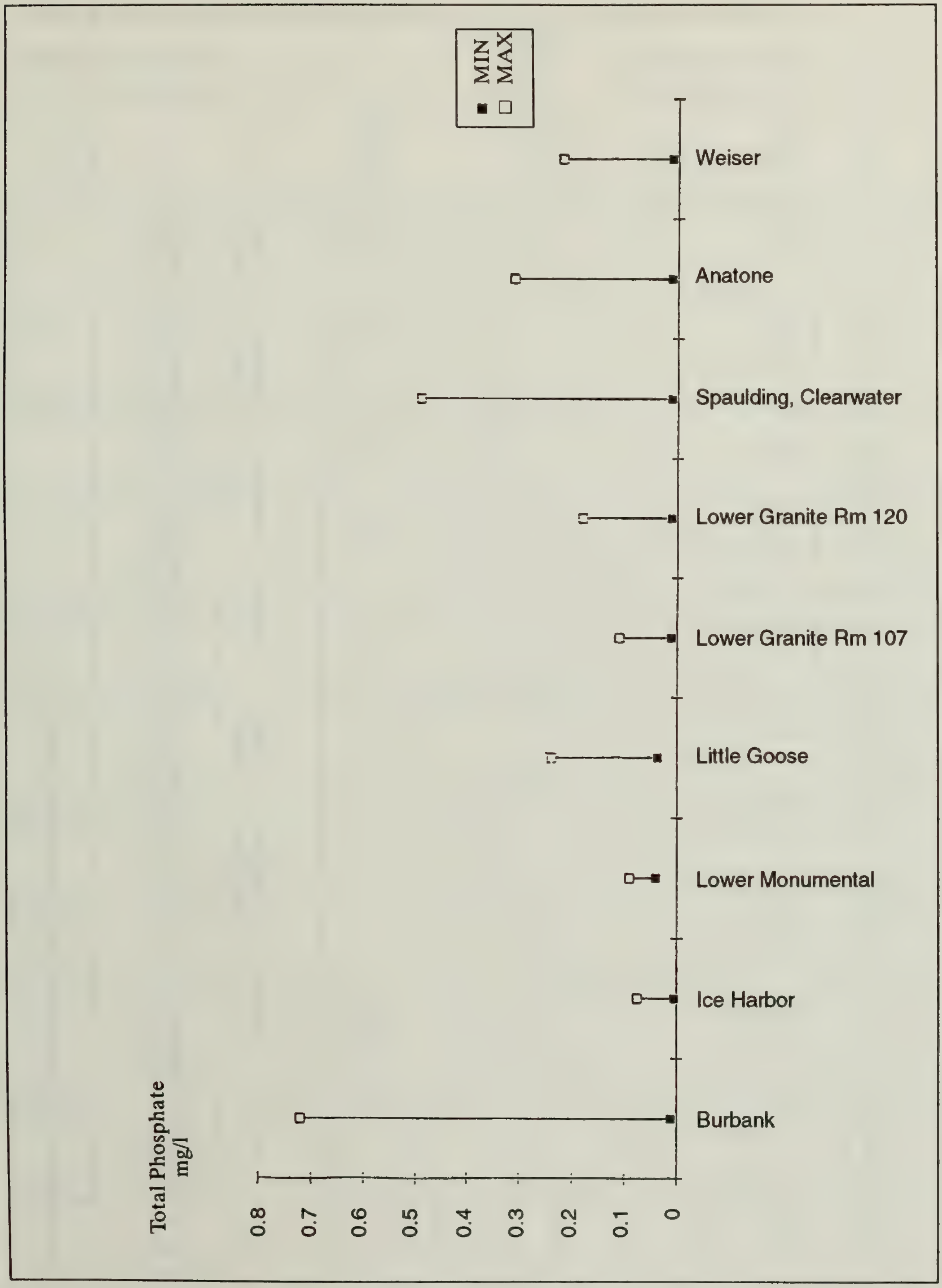


**Figure B–43.** Snake River & Clearwater Total Phosphate (mg/l)

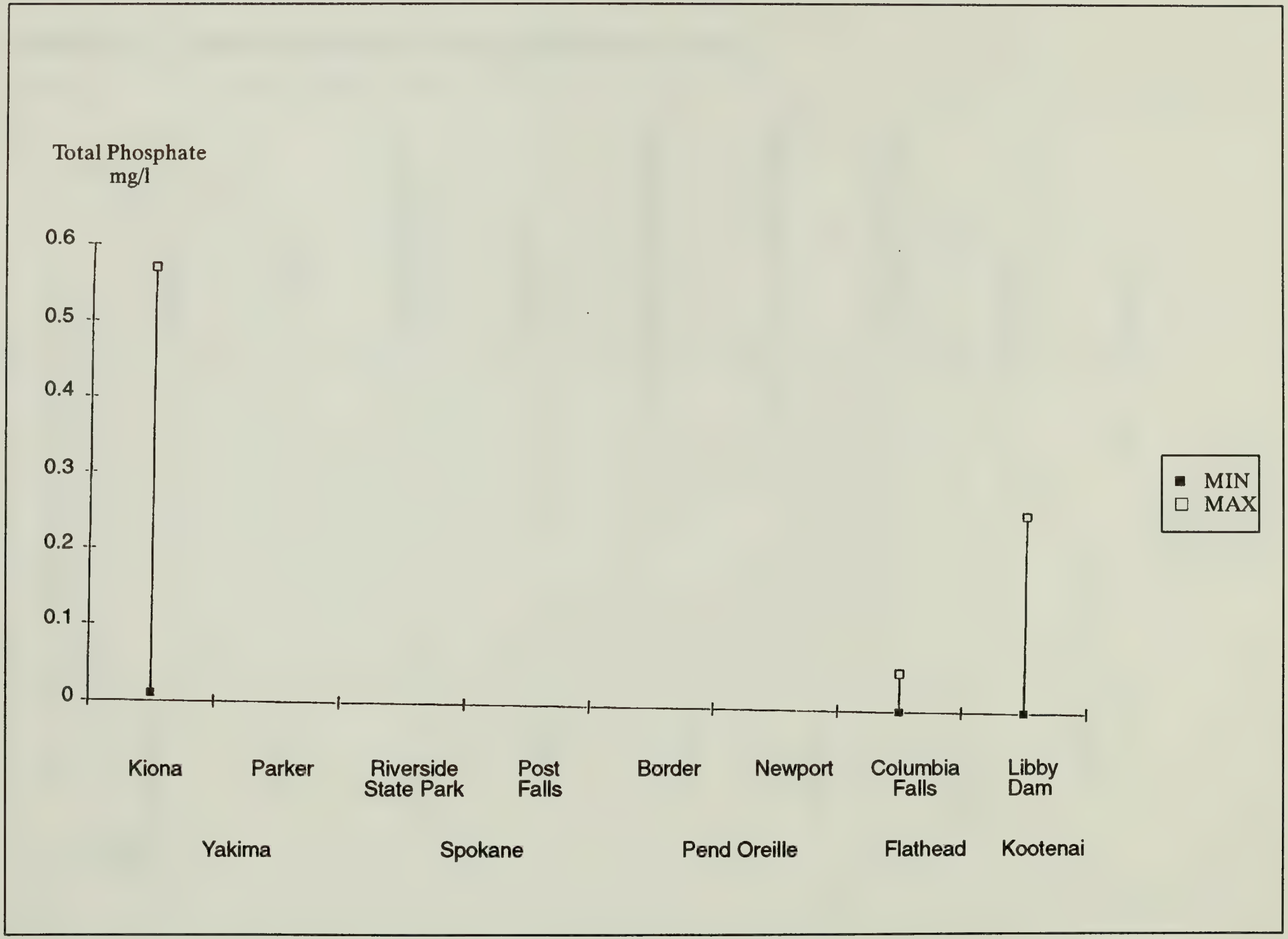


**Figure B–44. Tributaries Total Phosphate (mg/l)**

## Table B–3. Columbia Water Quality for Sites Warrendale and Vernita

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| RIVER: COLUMBIA | | | | | | RIVER: COLUMBIA | | | |
| SITE: WARRENDALE | | | | | | SITE: VERNITA | | | |
| BEG. YR: | | | 1988 | | 1975 | | 1975 | 1974 | 1975 |
| END YR: | | | 1990 | | 1979 | | 1990 | 1992 | 1990 |
| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
| TEMP | MIN | | 4 | | 2 | | 1.2 | 1.2 | 0.6 |
| | MAX | | 22.1 | | 20.8 | | 23.6 | 23.6 | 23.6 |
| | YR | | 3 | | 5 | | 14 | 19 | 16 |
| | SAMPLES | | NA | | 62 | | | 167 | 185 |
| COND | MIN | | 126 | | 0 | | 109 | 109 | 102 |
| | MAX | | 196 | | | | 190 | 190 | 190 |
| | YR | | 3 | | | | 15 | 19 | 16 |
| | SAMPLES | | | | | | | 189 | 185 |
| DO (mg/l) | MIN | | 8.2 | | 0 | | 7.6 | 7.6 | 7.5 |
| | MAX | | 13.3 | | | | 15.8 | 15.1 | 16 |
| | YR | | 3 | | | | 15 | 19 | 16 |
| | SAMPLES | | | | | | | 183 | 181 |
| pH (lab) | MIN | | 7.6 | | 6.9 | | 6.8 | 7.4 | 7.1 |
| | MAX | | 8.2 | | 8.5 | | 8.3 | 8.7 | 8.8 |
| | YR | | 3 | | 5 | | 15 | 13 | 16 |
| | SAMPLES | | | | 61 | | | 68 | 180 |
| Sed (susp mg/l) | MIN | | 6 | | 0 | | 0 | 0 | 0 |
| | MAX | | 25 | | 64 | | 50 | 50 | 24 |
| | YR | | 3 | | 4 | | 13 | 14 | 14 |
| | SAMPLES | | | | 38 | | | 88 | 147 |
| Turbidity | MIN | | 0.8 | | 1.1 | | 0.1 | 0.1 | 0 |
| | MAX | | 20 | | 25 | | 4.9 | 10 | 11 |
| | YR | | 3 | | 5 | | 13 | 19 | 16 |
| | SAMPLES | | | | 55 | | | 91 | 167 |
| Total Nitr NO2+NO | MIN | | 0 | | | | 0.01 | 0.01 | 0 |
| | MAX | | | | 0 | | 1.7 | 1.7 | 0.33 |
| | YR | | | | | | 6 | 18 | 15 |
| | SAMPLES | | | | | | | 69 | 88 |
| NH3+N (Total N) | MIN | | 0 | | 0 | | 0 | 0 | 0 |
| | MAX | | | | 0.11 | | 0.7 | 0.7 | 0.016 |
| | YR | | | | 4 | | 12 | 19 | 9 |
| | SAMPLES | | | | 35 | | | 102 | 88 |
| Total Pho | MIN | | 0.01 | | 0 | | 0.01 | 0.01 | 0 |
| | MAX | | 0.06 | | 0.18 | | 0.11 | 0.11 | 0.12 |
| | YR | | 3 | | 5 | | 15 | 19 | 16 |
| | SAMPLES | | | | 62 | | | 126 | 173 |
| Orthoph (dissolved) | MIN | | | | 0 | | 0 | 0 | 0 |
| | MAX | | 0 | | | | 0.15 | 0.05 | 0.11 |
| | YR | | | | | | 8 | 17 | 16 |
| | SAMPLES | | | | | | | 106 | 152 |
| Hardness | MIN | | 0 | | 44 | | 51 | | 42 |
| | MAX | | | | 94 | | 82 | | 95 |
| | YR | | | | 5 | | 8 | | 16 |
| | SAMPLES | | | | 55 | | | | 168 |

## Table B–4. Columbia Water Quality for Sites Umatilla and Rock Island

| RIVER: COLUMBIA | | | | | | RIVER: COLUMBIA | | | |
|---|---|---|---|---|---|---|---|---|---|
| SITE: UMATILLA | | | | | | SITE: ROCK ISLAND | | | |
| BEG. YR: | | | 1975 | | 1975 | | 1975 | 1976 | 1975 |
| ENDYR: | | | 1980 | | 1979 | | 1980 | 1977 | 1990 |
| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
| TEMP | MIN | | 1.6 | | 0.8 | | 1.8 | 4.7 | 0.8 |
| | MAX | | 21.5 | | 21.5 | | 20.5 | 24.4 | 23 |
| | YR | | 9 | | 9 | | 5 | 2 | 16 |
| | SAMPLES | | 75 | | 79 | | | 10 | 182 |
| COND | MN | | 97 | | 97 | | 95 | 118 | 95 |
| | MAX | | 244 | | 244 | | 220 | 141 | 220 |
| | YR | | 9 | | 9 | | 5 | 1 | 16 |
| | SAMPLES | | 75 | | 79 | | | 2 | 182 |
| DO (mg/l) | MIN | | 8.5 | | 8.5 | | 9.3 | 8.5 | 7.9 |
| | MAX | | 14.4 | | 14.4 | | 16 | 12.4 | 16.3 |
| | YR | | 9 | | 9 | | 5 | 2 | 16 |
| | SAMPLES | | 74 | | 78 | | | 11 | 182 |
| pH (lab) | MIN | | 7.1 | | 7.1 | | 7 | 6.9 | 6.8 |
| | MAX | | 8.8 | | 8.8 | | 9 | 7.7 | 9.2 |
| | YR | | 9 | | 9 | | 5 | 2 | 16 |
| | SAMPLES | | 73 | | 78 | | | 10 | 182 |
| Sed (susp mg/l) | MIN | | 0 | | 0 | | 0 | 0 | .1 |
| | MAX | | | | 394 | | | | 300 |
| | YR | | | | 9 | | | | 14 |
| | SAMPLES | | | | 77 | | | | 150 |
| Turbidity | MIN | | 0 | | 0.5 | | 1 | | 0.6 |
| | MAX | | | | 6.9 | | 11 | 0 | 11 |
| | YR | | | | 3 | | 5 | | 16 |
| | SAMPLES | | | | 27 | | | | 177 |
| Total Nitr NO2+NO | MIN | | 0 | | 0 | | 0.01 | 0.02 | 0 |
| | MAX | | 0.84 | | 0.8 | | 2.3 | 0.16 | 0.43 |
| | YR | | 9 | | 9 | | 4 | 2 | 16 |
| | SAMPLES | | 75 | | 77 | | | 7 | 88 |
| NH3 + N (Total N) | MIN | | 0 | | 0 | | 0 | 0.004 | 0 |
| | MAX | | 0.11 | | 0.08 | | 0.13 | 0.03 | 0.26 |
| | YR | | 9 | | 9 | | 5 | 2 | 16 |
| | SAMPLES | | 75 | | 75 | | | 9 | 175 |
| Total Pho | MIN | | 0.01 | | 0 | | 0.01 | 0.02 | 0.01 |
| | MAX | | 0.17 | | 0.17 | | 0.74 | 0.042 | 0.74 |
| | YR | | 9 | | 9 | | 5 | 2 | 16 |
| | SAMPLES | | 75 | | 77 | | | 9 | 169 |
| Ortho Ph (dissolved) | MIN | | 0.005 | | 0.01 | | 0 | 0.002 | 0 |
| | MAX | | 0.047 | | 0.047 | | 0.18 | 0.01 | 0.06 |
| | YR | | 3 | | 3 | | 5 | 2 | 16 |
| | SAMPLES | | 16 | | 27 | | | 5 | 173 |
| Hardness | MIN | | 0 | | 52 | | 49 | 0 | 49 |
| | MAX | | | | 80 | | 110 | | 110 |
| | YR | | | | 3 | | 2 | | 2 |
| | SAMPLES | | | | 13 | | | | 27 |

### Table B–5. Columbia Water Quality for Sites McNary and Grand Coulee

| RIVER: COLUMBIA | | | | | | RIVER: COLUMBIA | | | |
|---|---|---|---|---|---|---|---|---|---|
| SITE: MCNARY 2 * Tail race | | | | | | SITE: GRAND COULEE | | | |
| BEG. YR: | | 1975 | | 1974 | | 1975 | | 1974 | 1975 |
| ENDYR: | | 1992 | | 1976 | | 1980 | | 1990 | 1993 |
| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
| TEMP | MIN | | 5.3 | | 8.3 | | 0.8 | 0.6 | 0.6 |
| | MAX | | 22.2 | | 19.2 | | 19.1 | 19.3 | 19.3 |
| | YR | | 13 | | 3 | | 4 | 17 | 19 |
| | SAMPLES | | 34 | | 32 | | NA | 217 | 189 |
| COND | MIN | | 80 | | | | 110 | 110 | 80 |
| | MAX | | 222 | | 0 | | 197 | 248 | 248 |
| | YR | | 13 | | | | 5 | 17 | 19 |
| | SAMPLES | | 35 | | | | NA | 245 | 188 |
| DO (mg/l) | MIN | | 6.7 | | 10.1 | | 7.6 | 7.6 | 7.6 |
| | MAX | | 13.8 | | 14.1 | | 18 | 18 | 18 |
| | YR | | 13 | | 3 | | 5 | 17 | 19 |
| | SAMPLES | | 37 | | 32 | | NA | 143 | 188 |
| pH (lab) | MIN | | 6.9 | | | | 6.7 | 6.7 | 6.7 |
| | MAX | | 10.3 | | | | 8.5 | 9.2 | 9.2 |
| | YR | | 12 | | | | 5 | 17 | 19 |
| | SAMPLES | | 35 | | | | NA | 245 | 189 |
| Sed (susp mg/l) | MIN | | 0 | | | | 0 | 0 | .0 |
| | MAX | | | | | | | | 16 |
| | YR | | | | | | | | 17 |
| | SAMPLES | | | | | | | | 155 |
| Turbidity | MIN | | 2 | | | | 1 | 1 | 0.3 |
| | MAX | | 20 | | | | 9 | 4 | 9 |
| | YR | | 12 | | | | 5 | 3 | 19 |
| | SAMPLES | | 36 | | | | | 20 | 181 |
| Total Nitr NO2+NO | MIN | | 0.03 | | | | 0.01 | 0.01 | 0 |
| | MAX | | 1.55 | | | | 1.6 | 1.6 | 0.29 |
| | YR | | 8 | | | | 3 | 16 | 12 |
| | SAMPLES | | 14 | | | | | 153 | 94 |
| NH3+N (Total N) | MIN | | 0 | | | | 0 | 0 | 0 |
| | MAX | | | | | | 0.2 | 0.52 | 0.52 |
| | YR | | | | | | 5 | 17 | 19 |
| | SAMPLES | | | | | | | 241 | 180 |
| Total Pho | MIN | | 0.022 | | | | 0.01 | 0.01 | 0.01 |
| | MAX | | 0.132 | | | | 0.06 | 0.88 | 0.88 |
| | YR | | 7 | | | | 5 | 17 | 19 |
| | SAMPLES | | 13 | | | | | 136 | 173 |
| Ortho Ph (dissolved) | MIN | | 0.01 | | | | 0 | 0 | 0 |
| | MAX | | 0.14 | | | | 0.15 | 0.24 | 0.24 |
| | YR | | 7 | | | | 5 | 17 | 19 |
| | SAMPLES | | 13 | | | | | 139 | 178 |
| Hardness | MIN | | 39 | | | | 53 | 0 | 53 |
| | MAX | | 88 | | | | 85 | | 85 |
| | YR | | 9 | | | | 2 | | 2 |
| | SAMPLES | | 18 | | | | | | 27 |

## Table B–6. Columbia Water Quality for Sites Richland, Abv. Snake and Northport

RIVER: COLUMBIA
SITE: RICHLAND & ABV. SNAKE

RIVER: COLUMBIA
SITE: NORTHPORT

| BEG. YR: | | | 1979 | | 1975 | | 1975 | 1974 | 1975 |
|---|---|---|---|---|---|---|---|---|---|
| ENDYR: | | | 1990 | | 1992 | | 1991 | 1992 | 1981 |
| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
| TEMP | MIN | | 1.1 | | 1 | | 1.4 | 1.4 | 1.4 |
| | MAX | | 20.7 | | 20.7 | | 19 | 19.1 | 19.1 |
| | YR | | 12 | | 18 | | 17 | 19 | 11 |
| | SAMPLES | | | | 157 | | | 183 | 103 |
| COND | MIN | | 113 | | 113 | | 88 | 0 | 99 |
| | MAX | | 164 | | 260 | | 220 | 220 | 189 |
| | YR | | 12 | | 18 | | 17 | 19 | 11 |
| | SAMPLES | | | | 155 | | | 183 | 103 |
| DO (mg/l) | MIN | | 8.2 | | 8.2 | | 8.9 | 8.9 | 8.9 |
| | MAX | | 15 | | 15 | | 14.5 | 14.5 | 14.5 |
| | YR | | 12 | | 18 | | 14 | 16 | 9 |
| | SAMPLES | | | | 156 | | | 160 | 65 |
| pH (lab) | MIN | | 6.4 | | 7.5 | | 0.27 | 7.2 | 7 |
| | MAX | | 8.7 | | 8.8 | | 8.4 | 8.5 | 8.3 |
| | YR | | 12 | | 18 | | 17 | 14 | 11 |
| | SAMPLES | | | | 96 | | | 89 | 102 |
| Sed (susp mg/I) | MIN | | 2 | | 2 | | | 00 | 0 |
| | MAX | | 54 | | 54 | | 11.3 | 42 | 24 |
| | YR | | 11 | | 17 | | 15 | 18 | 7 |
| | SAMPLES | | | | 48 | | | 110 | 49 |
| Turbidity | MIN | | 0.4 | | 0.4 | | 0 | 0.2 | 0 |
| | MAX | | 13 | | 33 | | 5.4 | 5.4 | 4.1 |
| | YR | | 12 | | 18 | | 16 | 15 | 11 |
| | SAMPLES | | | | 105 | | | 93 | 98 |
| Total Nitr NO2+NO | MIN | | 0.02 | | 0.02 | | 0.02 | 0.02 | 0 |
| | MAX | | 3.1 | | 3.1 | | 0.68 | 0.68 | 0.68 |
| | YR | | 5 | | 6 | | 7 | 19 | 11 |
| | SAMPLES | | | | 25 | | | 76 | 98 |
| NH3+N (Total N) | MIN | | 0 | | 0 | | 0 | 0 | 0 |
| | MAX | | 0.11 | | 0.11 | | 2.4 | 0.2 | 0.2 |
| | YR | | 6 | | 10 | | 12 | 18 | 11 |
| | SAMPLES | | | | 25 | | | 103 | 95 |
| Total Pho | MIN | | 0.01 | | 0.009 | | 0 | 0 | 0 |
| | MAX | | 0.1 | | 0.2 | | 0.27 | 0.27 | 0.25 |
| | YR | | 12 | | 18 | | 16 | 19 | 11 |
| | SAMPLES | | | | 109 | | | 131 | 99 |
| OrthoPh (dissolved) | MIN | | 0 | | 0 | | 0 | 0.005 | 0 |
| | MAX | | 0.12 | | 0.06 | | 0.18 | 0.1 | 0.06 |
| | YR | | 2 | | 18 | | 5 | 18 | 7 |
| | SAMPLES | | | | 97 | | | 90 | 54 |
| Hardness | MIN | | 55 | | | | 0 | 0 | 24 |
| | MAX | | 78 | | | | | | 91 |
| | YR | | 5 | | | | | | 11 |
| | SAMPLES | | | | | | | | 98 |

## Table B–7. Snake River Water Quality for Sites Burbank and Lower Granite RM 107

RIVER: SNAKE RIVER
SITE: BURBANK

RIVER: SNAKE RIVER
SITE: LOWER GRANITE RM 107

| BEG. YR: | | 1975 | | | | 1978 | 1975 | 1975 | |
|---|---|---|---|---|---|---|---|---|---|
| END YR: | | 1990 | | | | 1989 | 1978 | 1977 | |
| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
| TEMP | MIN | | 0.8 | | | 13.6 | 2.5 | 19.4 | |
| | MAX | | 23.2 | | | 25.5 | 23 | 25.2 | |
| | YR | | 16 | | | 9 | 4 | 3 | |
| | SAMPLES | | NA | | | | 20 | NA | 78 |
| COND | MIN | | 74 | | | 101 | 65 | 145 | |
| | MAX | | 383 | | | 275 | 396 | 328 | |
| | YR | | 16 | | | 10 | 4 | 3 | |
| | SAMPLES | | NA | | | | 20 | NA | 75 |
| DO (mg/l) | MIN | | 6.2 | | | 4.4 | 7.5 | 2.3 | |
| | MAX | | 15.4 | | | 11.5 | 13.5 | 10.2 | |
| | YR | | 13 | | | 9 | 4 | 3 | |
| | SAMPLES | | NA | | | | 20 | NA | 64 |
| pH (lab) | MIN | | 6.1 | | | 7.1 | 7.1 | 6.3 | |
| | MAX | | 8.6 | | | 8.5 | 9 | 8.7 | |
| | YR | | 16 | | | 9 | 4 | 3 | |
| | SAMPLES | | NA | | | | 19 | NA | 71 |
| Sed (susp mg/l) | MIN | | 2 | | | 0 | 0 | 0 | |
| | MAX | | 222 | | | 0 | 0 | | |
| | YR | | 15 | | | 0 | 0 | | |
| | SAMPLES | | NA | | | | 0 | NA | |
| Turbidity (JTU/FTU) | MIN | | 0.6 | | | 1.2 | 0 | 0 | |
| | MAX | | 150 | | | 23 | 20 | | |
| | YR | | 16 | | | 9 | 4 | | |
| | SAMPLES | | NA | | | | 17 | NA | |
| Total Nitr NO2+NO | MIN | | 0.04 | | | 0.14 | 0.02 | 0.01 | |
| | MAX | | 1.5 | | | 1.5 | 0.94 | 0.14 | |
| | YR | | 8 | | | 4 | 4 | 3 | |
| | SAMPLES | | NA | | | | 8 | NA | 28 |
| NH3+N (Total N) | MIN | | 0 | | | 0 | 0.04 | 0.008 | |
| | MAX | | 0.69 | | | 0 | 0.32 | 0.75 | |
| | YR | | 13 | | | 0 | 4 | 3 | |
| | SAMPLES | | NA | | | | 0 | NA | 49 |
| Total Pho | MIN | | 0.01 | | | 0.05 | 0.01 | 0.02 | |
| | MAX | | 0.72 | | | 0.11 | 0.1 | 0.1 | |
| | YR | | 16 | | | 3 | 4 | 3 | |
| | SAMPLES | | NA | | | | 6 | NA | 51 |
| Ortho Ph (dissolved) | MIN | | 0 | | | 0.03 | 0 | 0.006 | |
| | MAX | | 0.21 | | | 0.6 | 0.15 | 0.04 | |
| | YR | | 7 | | | 2 | 4 | 3 | |
| | SAMPLES | | NA | | | | 5 | NA | 29 |
| Hardness | MIN | | 26 | | | 34 | 27 | 0 | |
| | MAX | | 140 | | | 100 | 120 | | |
| | YR | | 10 | | | 5 | 4 | | |
| | SAMPLES | | NA | | | | 12 | NA | |

## Table B–8. Snake River Water Quality for Sites Ice Harbor RM 18 and Lower Granite RM 120

RIVER: SNAKE RIVER
SITE: ICE HARBOR RM 18

RIVER: SNAKE RIVER
SITE: LOWER GRANITE RM 120

| BEG. YR: | | 1975 | | 1975 | 1975 | 1978 | | | |
|---|---|---|---|---|---|---|---|---|---|
| ENDYR: | | 1992 | | 1975 | 1990 | 1992 | | | |
| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
| TEMP | MIN | 2.3 | | 3.8 | 0.8 | 11.1 | 2.5 | | |
| | MAX | 25.2 | | 22.7 | 23.5 | 23.6 | 23 | | |
| | YR | 14 | | 3 | 16 | 9 | 4 | | |
| | SAMPLES | 43 | | 19 | 177 | 18 | NA | | |
| COND | MIN | 69 | | 90 | 74 | 57 | 65 | | |
| | MAX | 328.6 | | 378 | 400 | 303 | 396 | | |
| | YR | 14 | | 1 | 16 | 9 | 4 | | |
| | SAMPLES | 43 | | 14 | 178 | 18 | NA | | |
| DO (mg/l) | MIN | 5.5 | | 8.3 | 0 | 6.4 | 7.5 | | |
| | MAX | 12.5 | | 13.3 | 11.2 | | 13.5 | | |
| | YR | 14 | | 3 | 9 | | 4 | | |
| | SAMPLES | 43 | | 18 | | 18 | NA | | |
| pH (lab) | MIN | 6.9 | | 7.5 | 7.2 | 6.7 | 7.1 | | |
| | MAX | 8.7 | | 8.4 | 8.6 | 8.2 | 9 | | |
| | YR | 13 | | 3 | 16 | 9 | 4 | | |
| | SAMPLES | 41 | | 18 | 174 | 18 | NA | | |
| Sed (susp mg/l) | MIN | 0 | | 0 | 0 | 0 | 0 | | |
| | MAX | | | | 223 | 0 | | | |
| | YR | | | | 16 | | 0 | | |
| | SAMPLES | | | | 160 | | NA | | |
| Turbidity | MIN | 1.8 | | 0 | 0.6 | | 1.10 | | |
| | MAX | 16 | | | 150 | 52 | 20 | | |
| | YR | 13 | | | 16 | 5 | 4 | | |
| | SAMPLES | 40 | | | 160 | 10 | NA | | |
| Total Nitr NO2+NO | MIN | 0.1 | | 0.08 | 0 | 0.01 | 0.02 | | |
| | MAX | 1.4 | | 1.12 | | 1.7 | 0.94 | | |
| | YR | 5 | | 3 | | 5 | 4 | | |
| | SAMPLES | 7 | | 19 | | 9 | NA | | |
| NH3 + N (Total N) | MIN | 0 | | 0.01 | 0 | 0 | 0.04 | | |
| | MAX | | | 0.03 | | | 0.32 | | |
| | YR | | | 3 | | | 4 | | |
| | SAMPLES | | | 16 | | | NA | | |
| Total Pho | MIN | 0.004 | | 0.03 | 0 | 0.05 | 0.01 | | |
| | MAX | 0.075 | | 0.07 | | 0.18 | 0.1 | | |
| | YR | 4 | | 3 | | 4 | 4 | | |
| | SAMPLES | 6 | | 19 | | 8 | NA | | |
| Ortho Ph (dissolved) | MIN | < .01 | | 0.02 | 0 | 0.014 | 0 | | |
| | MAX | 0.072 | | 0.06 | | | 0.063 | | |
| | YR | 4 | | 3 | | 4 | | | |
| | SAMPLES | 6 | | 19 | | 8 | | | |
| Hardness | MIN | 35 | | | 26 | 32 | 0 | | |
| | MAX | 98 | | | 140 | 86 | | | |
| | YR | 8 | | | 16 | 4 | | | |
| | SAMPLES | 11 | | | 80 | 8 | | | |

## Table B–9. Snake River Water Quality for Sites Lower Monumental RM 44 and Anatone WA RM 167

| | | RIVER: SNAKE RIVER<br>SITE: LOWER MONUMENTAL RM 44 | | | | RIVER: SNAKE RIVER<br>SITE: ANATONE WA RM 167 | | | |
|---|---|---|---|---|---|---|---|---|---|
| BEG. YR: | | 1978 | | 1975 | | | 1975 | | |
| ENDYR: | | 1992 | | 1975 | | | 1990 | | |
| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
| TEMP | MIN | 14.5 | | 21 | | | 1 | | |
| | MAX | 23.3 | | 21 | | | 24 | | |
| | YR | 14 | | 1 | | | 16 | | |
| | SAMPLES | 16 | | 5 | | | NA | | |
| COND | MIN | 73 | | 27 | | | 63 | | |
| | MAX | 245 | | 77 | | | 681 | | |
| | YR | 14 | | 1 | | | 16 | | |
| | SAMPLES | 16 | | 5 | | | NA | | |
| DO (mg/l) | MIN | 5.4 | | 8.3 | | | 6.2 | | |
| | MAX | 11 | | 9.2 | | | 13.8 | | |
| | YR | 14 | | 1 | | | 6 | | |
| | SAMPLES | 16 | | 5 | | | NA | | |
| pH (lab) | MIN | 6.76 | | 7.5 | | | 6.5 | | |
| | MAX | 7.9 | | 7.6 | | | 8.7 | | |
| | YR | 14 | | 1 | | | 6 | | |
| | SAMPLES | 15 | | 5 | | | NA | | |
| Sed (susp mg/l) | MIN | 0 | | 0 | | | 2 | | |
| | MAX | | | | | | 245 | | |
| | YR | | | | | | 5 | | |
| | SAMPLES | | | | | | NA | | |
| Turbidity (JTU/FTU) | MIN | 2.5 | | 0 | | | 0 | | |
| | MAX | 13 | | | | | 60 | | |
| | | 21 | | | | | 6 | | |
| | SAMPLES | 14 | | | | | NA | | |
| Total Nitr NO2+NO | MIN | 0.02 | | 0.08 | | | 0.01 | | |
| | MAX | 1.4 | | 0.08 | | | 1.1 | | |
| | YR | 7 | | 1 | | | 6 | | |
| | SAMPLES | 6 | | 5 | | | NA | | |
| NH3 + N (Total N) | MIN | 0 | | 0.02 | | | 0 | | |
| | MAX | | | 0.04 | | | 0.12 | | |
| | YR | | | 1 | | | 6 | | |
| | SAMPLES | | | 5 | | | NA | | |
| Total Pho | MIN | 0.04 | | 0.046 | | | 0.01 | | |
| | MAX | 0.09 | | 0.064 | | | 0.31 | | |
| | YR | 4 | | 1 | | | 6 | | |
| | SAMPLES | 5 | | 5 | | | NA | | |
| Ortho Ph (dissolved) | MIN | <.01 | | 0.02 | | | 0 | | |
| | MAX | 0.07 | | 0.02 | | | | | |
| | YR | 4 | | 1 | | | | | |
| | SAMPLES | 5 | | 5 | | | | | |
| Hardness | MIN | 35 | | 0 | | | 41 | | |
| | MAX | 76 | | | | | 150 | | |
| | YR | 6 | | | | | 6 | | |
| | SAMPLES | 8 | | | | | NA | | |

## Table B–10. Snake River Water Quality for Sites Little Goose RM 83 and Weiser ID (RM351.3)

RIVER: SNAKE RIVER
SITE: LITTLE GOOSE RM 83

| | ACOE | USGS | EPA |
|---|---|---|---|
| BEG. YR: | 1978 | 1975 | 1975 |
| ENDYR: | 1992 | 1975 | 1990 |

RIVER: SNAKE RIVER
SITE: WEISER ID (RM 351.3)

| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
|---|---|---|---|---|---|---|---|---|---|
| TEMP | MIN | 14.8 | | 19.5 | | | 1 | | |
| | MAX | 27.3 | | 21 | | | 27 | | |
| | YR | 9 | | 1 | | | 16 | | |
| | SAMPLES | 15 | | 5 | | | NA | | |
| COND | MIN | 96 | | 24 | | | 97 | | |
| | MAX | 268 | | 73 | | | 572 | | |
| | YR | 9 | | 1 | | | 16 | | |
| | SAMPLES | 15 | | 5 | | | NA | | |
| DO (mg/l) | MIN | 4.2 | | 7.2 | | | 5.8 | | |
| | MAX | 10.5 | | 10.4 | | | 14.2 | | |
| | YR | 9 | | 1 | | | 13 | | |
| | SAMPLES | 15 | | 5 | | | NA | | |
| pH (lab) | MIN | 7.2 | | 7.3 | | | 7.5 | | |
| | MAX | 8.4 | | 8 | | | 9.1 | | |
| | YR | 9 | | 1 | | | 13 | | |
| | SAMPLES | 13 | | 5 | | | NA | | |
| Sed (susp mg/l) | MIN | 0 | | 0 | | | 5 | | |
| | MAX | | | | | | 211 | | |
| | YR | | | | | | 10 | | |
| | SAMPLES | | | | | | NA | | |
| Turbidity (JTU/FTU) | MIN | 1.4 | | 0.6 | | | | | |
| | MAX | 9.7 | | | | | 40 | | |
| | YR | 9 | | | | | 13 | | |
| | SAMPLES | 14 | | | | | NA | | |
| Total Nitr NO2+NO | MIN | 0.08 | | 0.02 | | | 0.01 | | |
| | MAX | 1.35 | | 0.08 | | | 1.8 | | |
| | YR | 5 | | 1 | | | 8 | | |
| | SAMPLES | 9 | | 5 | | | NA | | |
| NH3 + N (Total N) | MIN | 0 | | 0.02 | | | 0 | | |
| | MAX | | | 0.05 | | | 0.23 | | |
| | YR | | | 1 | | | 9 | | |
| | SAMPLES | | | 5 | | | NA | | |
| Total Pho | MIN | 0.06 | | 0.036 | | | 0.01 | | |
| | MAX | 0.238 | | 0.052 | | | 0.22 | | |
| | YR | 4 | | 1 | | | 13 | | |
| | SAMPLES | 8 | | 5 | | | NA | | |
| Ortho Ph (dissolved) | MIN | 0.02 | | 0.01 | | | 0.03 | | |
| | MAX | 0.07 | | 0.02 | | | 0.31 | | |
| | YR | 4 | | 1 | | | 2 | | |
| | SAMPLES | 8 | | 5 | | | NA | | |
| Hardness | MIN | 44 | | 0 | | | 89 | | |
| | MAX | 88 | | | | | 210 | | |
| | YR | 5 | | | | | 10 | | |
| | SAMPLES | 7 | | | | | NA | | |

## Table B–11. Clearwater and Yakima Water Quality Appendix for Sites Spaulding RM 11.6 and Kiona RM 29.9 (37A)

| RIVER: CLEARWATER RIVER | | | | | | RIVER: YAKIMA | | | |
|---|---|---|---|---|---|---|---|---|---|
| SITE: SPAULDING RM 11.6 | | | | | | SITE: KIONA RM 29.9 (37A) | | | |
| BEG. YR: | | | 1975 | | | | 1975 | | 1975 |
| BEG. YR: | | | 1990 | | | | 1991 | | 1986 |
| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
| TEMP | MIN | | 0 | | | | 0 | | 0 |
| | MAX | | 21.2 | | | | 27.3 | | 27.3 |
| | YR | | 16 | | | | 16 | | 12 |
| | SAMPLES | | NA | | | | NA | | 141 |
| COND | MIN | | 19 | | | | 107 | | 110 |
| | MAX | | 138 | | | | 490 | | 435 |
| | YR | | 16 | | | | 16 | | 12 |
| | SAMPLES | | NA | | | | NA | | 137 |
| DO (mg/l) | MIN | | 4.8 | | | | 7.5 | | |
| | MAX | | 13.9 | | | | 16.8 | | |
| | YR | | 12 | | | | 15 | | |
| | SAMPLES | | NA | | | | NA | | |
| pH (lab) | MIN | | 0.1 | | | | 0.05 | | 6.8 |
| | MAX | | 8.3 | | | | 9.2 | | 9.2 |
| | YR | | 12 | | | | 16 | | 12 |
| | SAMPLES | | NA | | | | NA | | 132 |
| Sed (susp mg/I) | MIN | | 1 | | | | 4 | | 1 |
| | MAX | | 1070 | | | | 490 | | 256 |
| | YR | | 15 | | | | 13 | | 11 |
| | SAMPLES | | NA | | | | NA | | 94 |
| Turbidity | MIN | | 0.3 | | | | 0 | | 0 |
| | MAX | | 190 | | | | 130 | | 130 |
| | YR | | 14 | | | | 16 | | 12 |
| | SAMPLES | | NA | | | | NA | | 127 |
| Total Nitr NO2+NO | MIN | | 0 | | | | 0.12 | | |
| | MAX | | 3.9 | | | | 1.9 | | |
| | YR | | 4 | | | | 9 | | |
| | SAMPLES | | NA | | | | NA | | |
| NH3+N (Total N) | MIN | | 0 | | | | 0 | | |
| | MAX | | 2.2 | | | | 2.9 | | |
| | YR | | 9 | | | | 14 | | |
| | SAMPLES | | NA | | | | NA | | |
| Total Pho | MIN | | 0.01 | | | | 0.01 | | |
| | MAX | | 0.49 | | | | 0.57 | | |
| | YR | | 13 | | | | 17 | | |
| | SAMPLES | | NA | | | | NA | | |
| Ortho Ph (dissolved) | MIN | | 0.03 | | | | 0.09 | | |
| | MAX | | 0.18 | | | | 0.37 | | |
| | YR | | 3 | | | | 7 | | |
| | SAMPLES | | NA | | | | NA | | |
| Hardness | MIN | | 0 | | | | 0 | | 44 |
| | MAX | | | | | | | | 170 |
| | YR | | | | | | | | 12 |
| | SAMPLES | | | | | | | | 90 |

### Table B–12. Yakima and Spokane Water Quality for Sites Parker 37A190 and Riverside Stat

RIVER: YAKIMA
SITE: PARKER 37A190

RIVER: SPOKANE RIVER
SITE: RIVERSIDE STAT

| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
|---|---|---|---|---|---|---|---|---|---|
| BEG. YR: | | | | | 1975 | | | | 1986 |
| END YR: | | | | | 1986 | | | | 1993 |
| TEMP | MIN | | | | 0 | | | | 1 |
| | MAX | | | | 9.8 | | | | 19.2 |
| | YR | | | | 12 | | | | 8 |
| | SAMPLES | | | | 158 | | | | 78 |
| COND | MIN | | | | 73 | | | | 59 |
| | MAX | | | | 228 | | | | 497 |
| | YR | | | | 12 | | | | 8 |
| | SAMPLES | | | | 158 | | | | 78 |
| DO (mg/l) | MIN | | | | | | | | |
| | MAX | | | | | | | | 0 |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| pH (lab) | MIN | | | | 6.5 | | | | 6.8 |
| | MAX | | | | 9.1 | | | | 8.7 |
| | YR | | | | 12 | | | | 8 |
| | SAMPLES | | | | 157 | | | | 77 |
| Sed (susp mg/l) | MIN | | | | 1 | | | | 1 |
| | MAX | | | | 76 | | | | 1200 |
| | YR | | | | 10 | | | | 8 |
| | SAMPLES | | | | 95 | | | | 74 |
| Turbidity | MIN | | | | 2 | | | | 0.5 |
| | MAX | | | | 49 | | | | 210 |
| | YR | | | | 12 | | | | 8 |
| | SAMPLES | | | | 143 | | | | 74 |
| Total Nitr NO2+NO | MIN | | | | | | | | |
| | MAX | | | | | | | | 0 |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| NH3+N (Total N) | MIN | | | | | | | | |
| | MAX | | | | | | | | 0 |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| Total Pho | MIN | | | | | | | | |
| | MAX | | | | | | | | 0 |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| Ortho Ph (dissolved) | MIN | | | | | | | | |
| | MAX | | | | | | | | 0 |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| Hardness | MIN | | | | 27 | | | | 22 |
| | MAX | | | | 58 | | | | 121 |
| | YR | | | | 1 | | | | 6 |
| | SAMPLES | | | | 18 | | | | 57 |

### Table B–13. Spokane and Pendorei Water Quality for Sites Post Falls 54A190 and Border 62A080

| RIVER: SPOKANE | | | | | | RIVER: PENDOREI | | | |
|---|---|---|---|---|---|---|---|---|---|
| SITE: NEAR POST FALLS 54A190 | | | | | | SITE: BORDER 62A080 | | | |
| BEG. YR: | | | | | 1975 | | | | 1986 |
| END YR: | | | | | 1986 | | | | 1993 |
| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
| TEMP | MIN | | | | 0.4 | | | | 0.1 |
| | MAX | | | | 25 | | | | 22.8 |
| | YR | | | | 12 | | | | 7 |
| | SAMPLES | | | | 147 | | | | 75 |
| COND | MIN | | | | 42 | | | | 127 |
| | MAX | | | | 135 | | | | 204 |
| | YR | | | | 12 | | | | 7 |
| | SAMPLES | | | | 148 | | | | 75 |
| DO (mg/l) | MIN | | | | | | | | |
| | MAX | | | | | | | | |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| pH (lab) | MIN | | | | 6.1 | | | | 6.4 |
| | MAX | | | | 8.4 | | | | 8.6 |
| | YR | | | | 12 | | | | 7 |
| | SAMPLES | | | | 143 | | | | 75 |
| Sed (susp mg/l) | MIN | | | | 0 | | | | 0 |
| | MAX | | | | 75 | | | | 42 |
| | YR | | | | 11 | | | | 3 |
| | SAMPLES | | | | 102 | | | | 24 |
| Turbidity | MIN | | | | 0 | | | | 0.3 |
| | MAX | | | | 35 | | | | 15 |
| | YR | | | | 12 | | | | 7 |
| | SAMPLES | | | | 122 | | | | 73 |
| Total Nitr NO2+NO | MIN | | | | | | | | |
| | MAX | | | | | | | | |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| NH3 + N (Total N) | MIN | | | | | | | | |
| | MAX | | | | | | | | |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| Total Pho | MIN | | | | | | | | |
| | MAX | | | | | | | | |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| Ortho Ph (dissolved) | MIN | | | | | | | | |
| | MAX | | | | | | | | |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| Hardness | MIN | | | | 0 | | | | 67 |
| | MAX | | | | 84 | | | | 91 |
| | YR | | | | 12 | | | | 7 |
| | SAMPLES | | | | 75 | | | | 74 |

### Table B–14. Pend Oreille and Flathead River Water Quality for Sites Newport and Near Columbia Falls

RIVER: PEND OREILLE
SITE: @ NEWPORT

RIVER: FLATHEAD RIVER
SITE: NEAR COLUMBIA FALLS

| | | ACOE | USGS | EPA | WDOE | ACOE | USGS | EPA | WDOE |
|---|---|---|---|---|---|---|---|---|---|
| BEG. YR: | | | | | 1975 | | 1986 | | |
| ENDYR: | | | | | 1986 | | 1993 | | |
| TEMP | MIN | | | | 0 | | 0 | | |
| | MAX | | | | 23.6 | | 16.5 | | |
| | YR | | | | 12 | | 11 | | |
| | SAMPLES | | | | 127 | | NA | | |
| COND | MIN | | | | 125 | | 50 | | |
| | MAX | | | | 240 | | 245 | | |
| | YR | | | | 12 | | 11 | | |
| | SAMPLES | | | | 127 | | NA | | |
| DO (mg/l) | MIN | | | | | | 9.1 | | |
| | MAX | | | | | | 13.2 | | |
| | YR | | | | | | 4 | | |
| | SAMPLES | | | | | | NA | | |
| pH (lab) | MIN | | | | 6.9 | | 7.3 | | |
| | MAX | | | | 9 | | 8.6 | | |
| | YR | | | | 10 | | 4 | | |
| | SAMPLES | | | | 103 | | NA | | |
| Sed (susp mg/l) | MIN | | | | 1 | | 1 | | |
| | MAX | | | | 16 | | 524 | | |
| | YR | | | | 9 | | 4 | | |
| | SAMPLES | | | | 90 | | NA | | |
| Turbidity | MIN | | | | 1 | | 0 | | |
| | MAX | | | | 35 | | 20 | | |
| | YR | | | | 12 | | 4 | | |
| | SAMPLES | | | | 122 | | NA | | |
| Total Nitr NO2+NO | MIN | | | | | | 0.01 | | |
| | MAX | | | | | | 0.29 | | |
| | YR | | | | | | 4 | | |
| | SAMPLES | | | | | | NA | | |
| NH3+N (Total N) | MIN | | | | | | 0.01 | | |
| | MAX | | | | | | 0.04 | | |
| | YR | | | | | | 2 | | |
| | SAMPLES | | | | | | NA | | |
| Total Pho | MIN | | | | | | 0 | | |
| | MAX | | | | | | 0.05 | | |
| | YR | | | | | | 4 | | |
| | SAMPLES | | | | | | NA | | |
| Ortho Ph (dissolved) | MIN | | | | | | 0 | | |
| | MAX | | | | | | | | |
| | YR | | | | | | | | |
| | SAMPLES | | | | | | | | |
| Hardness | MIN | | | | 28 | | 69 | | |
| | MAX | | | | 91 | | 130 | | |
| | YR | | | | 5 | | 4 | | |
| | SAMPLES | | | | 33 | | NA | | |

### Table B–15. Kootenai Water Quality for Site Libby Dam, Near Libby, MT RM 221

RIVER: KOOTENAI

SITE: LIBBY DAM, NEAR LIBBY, MT RM 221

| | |
|---|---|
| BEG. YR: | 1975 |
| END YR: | 1991 |

| | | ACOE | USGS | EPA | WDOE |
|---|---|---|---|---|---|
| TEMP | MIN | 1.6 | | | |
| | MAX | 18.5 | | | |
| | YR | 17 | | | |
| | SAMPLES | NA | | | |
| COND | MIN | 175 | | | |
| | MAX | 330 | | | |
| | YR | 17 | | | |
| | SAMPLES | NA | | | |
| DO (mg/l) | MIN | 7.7 | | | |
| | MAX | 17.5 | | | |
| | YR | 17 | | | |
| | SAMPLES | NA | | | |
| pH (lab) | MIN | 7.6 | | | |
| | MAX | 8.7 | | | |
| | YR | 17 | | | |
| | SAMPLES | NA | | | |
| Sed (susp mg/l) | MIN | 0 | | | |
| | MAX | | | | |
| | YR | | | | |
| | SAMPLES | | | | |
| Turbidity | MIN | 1 | | | |
| | MAX | 8 | | | |
| | YR | 2 | | | |
| | SAMPLES | NA | | | |
| Total Nitr NO2+NO | MIN | 0.01 | | | |
| | MAX | 0.24 | | | |
| | YR | 15 | | | |
| | SAMPLES | NA | | | |
| NH3+N (Total N) | MIN | 0 | | | |
| | MAX | 0.61 | | | |
| | YR | 9 | | | |
| | SAMPLES | NA | | | |
| Total Pho | MIN | 0 | | | |
| | MAX | 0.26 | | | |
| | YR | 17 | | | |
| | SAMPLES | NA | | | |
| Orthoph (dissolved) | MIN | 0 | | | |
| | MAX | 0.31 | | | |
| | YR | 8 | | | |
| | SAMPLES | NA | | | |
| Hardness | MIN | 96 | | | |
| | MAX | 160 | | | |
| | YR | 8 | | | |
| | SAMPLES | NA | | | |

# TECHNICAL EXHIBIT C

# OPERATIONAL AND STRUCTURAL WATER QUALITY ENHANCEMENT TECHNIQUES

## C–1 RULE CURVE CHANGE

Modification of the rule curve relies on changing the hydraulic residence time of the inflow in the pool to control poor quality inflow. This can be accomplished by maintaining a small pool through most of the flood control season and allowing undesirable inflows entering the reservoir to be flushed through. The reservoir is then allowed to fill to summer pool elevation later in the season, when the inflow water quality is typically better.

If inflow quality is governed more by discharge than season, maintaining a large pool with a greater retention time may allow suspended material to settle in headwaters, and thereby improve the quality of the main portion of the reservoir. However, increased residence time to allow settling of suspended solids may enhance thermal stratification and subsequent depletion of oxygen in the hypolimnion. Water withdrawn from lower elevations of the reservoir could, in this case, result in poor downstream quality that may offset other benefits of the rule curve changes.

By the same token, delay in reservoir filling may also increase erosion of the exposed lake bottom due to wave action and the lack of a stabilizing plant cover.

A variation of this technique is to change the minimum pool elevation of the reservoir and allow additional storage for water quality maintenance or conservation of a quality resource, such as cool water for downstream release. Adjusting the rule curve may also benefit the wildlife of the reservoir by creating additional habitat at critical times and controlling aquatic plant growth.

## C–2 INFLOW ROUTING

Undesirable inflows are identified and routed through the reservoir to minimize impacts to the existing reservoir water quality, similar to the routing of flood flows through a basin. Selective withdrawal capability greatly enhances this technique if the inflow occurs at some intermediate depth. Other outlet works (e.g. spillways or sluiceways) may also be used to release the inflow.

## C–3 CONCENTRATION OF FLOW THROUGH ONE GATE

For a given release condition, gates are usually operated the same to achieve as even a flow distribution downstream as possible. This helps prevent scour and erosion to the stilling basin and downstream, or provides the best flow conditions for ship movement. During low–flow periods, when dissolved oxygen is generally low, such a danger potential does not exists. As a result, release of flows may be made through a smaller number of gates to increase unit discharge, increase turbulence in the stilling basin, and enhance reaeration.

## C–4 SELECTIVE WITHDRAWAL

Thermal stratification during summer isolates the hypolimnion from the surface layers. The oxygen demand associated with decomposition of organics in the hypolimnion usually results in the development of anoxic conditions, which allow phosphorous from internal sinks to be released and contribute to the eutrophication of the lake. Selective evacuation of the hypolimnion can be used to remove excess phosphorus concentrations and reduce eutrophication rate. Selective withdrawal can also apply to multiple level outlets when water at different temperatures can be mixed before release.

## C–5 PNEUMATIC DESTRATIFICATION

This technique is used to mix hypolimnetic with epilimnetic water to prevent anoxic conditions from occurring. It is particularly useful when it is desirable to maintain uniform conditions through the water column. For example, algae blooms can be reduced by limiting the amount of sunlight the algae receive (by circulating the algae to below the photic zone). Pneumatic destratification relies on linear or point air diffuser system apparatus strategically positioned on the lake bottom and supplied by a compressor located on the shore. The air bubbles released through the diffusers rise through the water column and create an upward water current that spreads out laterally upon reaching the surface. Circulation cells are set up to replace the upward moving water, and eventually the water column becomes mixed down to the level of the diffuser(s).

Other methods to mechanically enrich storage water with oxygen include aeration–oxygenation systems and turbine venting when, because of stratification, the hypolimnion may become devoid of oxygen and therefore allow oxidized elements and compounds to be reduced into solution. These constituents, such as iron, manganese, and hydrogen sulfide, are toxic to aquatic life. Hypolimnetic aeration or oxygenation is a technique that introduces oxygen in the hypolimnion without significantly impacting the thermal stratification.

Water released from the hypolimnion during the stratified periods may be low in dissolved oxygen (DO). As the flow passes through the turbines, conditions become very favorable for reaeration to occur. Turbine venting allows oxygen to enter the draft tube downstream of the turbines and increase the DO in the released water. Secondary impacts of increased DO in the water downstream, such as reduction in iron, manganese, or hydrogen sulfide, may also be achieved through this technique.

## C–6 UNDERWATER DAMS

Installation of a submerged barrier curtain or dam on a portion of the reservoir can be used to retain the cool water during the summer by preventing its release downstream. This technique prevents movement of the hypolimnion and effectively create a trap in the reservoir for cool water. Care must be exercised to get rid of the sediments that may also be trapped by the submerged structure.

A variation of this technique relies on submerged skimming weir, when water is released from the epilimnion. A submerged skimming weir is designed to extend to the top of the reservoir thermocline and prevent the withdrawal of the hypolimnion, which may be low in oxygen or contains undesirable trace constituents.

## C–7 EMPTYING INDIVIDUAL RESERVOIRS EVERY DECADE

Suggestions have been made in other parts of the country, in conjunction with a special fisheries management operation, to grow vegetation in the lake bottom for cover after filling, to reduce existing fish stocks and replace them after filling with a more desirable mix of species, and to improve water quality. Added advantages would result if such an operation could be used in conjunction with drawdown for dam safety inspections and maintenance.

The practicality of this proposal may be limited, except for run–of–the–river reservoirs that can be refilled in less than a year. This operation is similar in many respects to the Lower Snake River reservoir drawdown alternatives.

## C–8 USE OF SURFACE WATER PUMPS

Surface water pumps can sometimes be used to aerate releases from a reservoir and reduce its temperature in the order of 1 to 2 degrees C, depending on the temperature profile of the reservoir. By the same token, pumps could be used to warm the releases more than 2 to 3 degrees C (TVA, 1990).

However, the effectiveness of using surface water pumps to mitigate temperature effects rather than for aeration needs to be evaluated on a case–by–case basis. If too many pumps are installed, bottom sediments could be stirred up, which can reduce the effectiveness of aeration and cause problems with deposited sediments and hydrogen sulfide.

## C–9 SINGLE–PURPOSE SYSTEM OPERATION

The most efficient plan to maintain or enhance water quality in the Columbia River and its tributaries is to operate the river system with water quality as the single purpose, regardless of impacts on other uses. System operation in such a single–purpose context had been qualitatively evaluated by the Corps of Engineers in the early 1980s as part of the Columbia River and Tributaries Study (CR&T). Structural and nonstructural strategies were recommended for the following water–related development activities that have common effects upon river ecosystems: power generation, irrigation, flood damage reduction and navigation. Recommended strategies that are found to still be applicable are summarized below.

## C–9.1 Power Generation

### C–9.1.1 Nonstructural Alternatives

Eliminate or lessen the need for further system development. This could be achieved by:

- adopting a policy of reducing excessive energy use;
- promoting energy conservation;
- restricting the development of industries requiring large amounts of electricity;
- stressing continuous operation of industries to level out demand and reduce the need for peaking;
- reversing the rate structure to discourage consumption; and
- promoting research on alternative energy sources.

The impact of fluctuating pool levels and flows on water quality should be quantitatively established for each river segment. This information could then be used to develop new regulation procedures or change operational strategies to minimize impacts. The system should also be operated for maximum balance of hydraulic capabilities between existing projects to reduce river fluctuations. Vegetation that is resistant to frequent inundation and dewatering should be established along reservoir shorelines to reduce the aesthetic, ecosystem and turbidity impacts associated with peaking.

Segments of the system which are susceptible to adverse impacts by thermal plants should be identified. Developments in these areas should be restricted to plants with reuse systems. Development of reuse or evaporative cooling systems should be stressed for thermal plants. Once–through cooling should be restricted to situations which permit multiple use of the diverted water, e.g. aquaculture facilities, irrigation, etc.

### C–9.1.2 Structural Alternatives

Reregulation facilities should be constructed where necessary to permit full peaking development without causing unacceptable downstream water flow and level fluctuations. Additional storage should be developed at existing, on and offstream sites to improve the hydraulic balance between projects. Pumped storage should be considered, where appropriate.

## C–9.2 Irrigation

Recommendations were to address streamflows depletion due to greater consumptive use of water, and increased volumes of poor quality irrigation return flows.

### C–9.2.1 Nonstructural Alternatives

In critical areas where flows are already depleted, irrigation development should be limited to present levels. Unobligated storage in existing projects should be allocated for instream flow or irrigation use. If necessary, reauthorization of projects should be considered to achieve this purpose. Water diverted for once–through thermal plant cooling systems should be utilized.

To improve the quality of irrigation return flows, more drastic legislative action should be taken to enforce the application of measures to reduce pollutant inputs. An incentive program should be implemented for applying erosion and sediment control practices on irrigated lands. This could be in the form of low–interest loans or cost–sharing.

Improved irrigation practices can use less water by being more efficient, and can reduce surface runoff. Research efforts leading to the development of new technology and the implementation of more efficient methods should be supported. Simulation models for predicting sediment, nutrient, and biocide losses associated with specific irrigation practices should be developed and/or refined. This would allow the selection of methods which will have the least impact in water quality limited areas.

### C–9.2.2 Structural Alternatives

Some form of treatment of irrigation return flows is required. This could include the construction of sediment retention basin, use of chemical flocculation, vegetative filter strips, etc. Sediment control methods must be implemented; farming practices involving minimum tillage should be emphasized; and land forming and shaping should be considered where applicable.

Water could be used more efficiently by applying irrigation methods appropriate to the specific land form. Irrigation runoff recovery systems, and sprinkler, trickle, and subsurface irrigation methods should be emphasized. Flood irrigation would be restricted to situations where the slope and soil characteristics permit a high distribution efficiency. Wide flooding should be discouraged.

Irrigation return flow volume could be reduced by using deep–well injection to dispose of runoff. This would result in a smaller amount of poor quality water being returned to the river and could be a significant groundwater recharge source in some areas. In areas where it is practicable (e.g. Upper Snake Basin), groundwater recharge during high flows should be considered. During the irrigation season, groundwater could then be used as an alternative to surface water withdrawal.

Additional storage in existing projects and new on and offstream storage should be developed. In–reservoir techniques for minimizing water quality problems should be implemented as needed. This includes mechanical mixing, aeration, oxygenation, destratification, etc.

## C–9.3 Flood Damage Reduction

### C–9.3.1 Structural Alternatives

- In–channel modifications could be reduced or avoided in many cases by the use of various alternative designs involving construction of offstream facilities. Such facilities at levees, floodways, retarding basins, building floodproofing and land treatment should be incorporated to avoid actual channel modification. When in–channel modifications are necessary, measures to mitigate adverse impacts should be implemented. These include:

- during channel construction, the alignment should follow a natural pattern which considers the type of existing stream, the required hydraulic capacity, and comparison with upstream and downstream sections;

- in stream sections passing through highly erodible soils, an alternative course may be desirable if an alignment through more stable soil exists;

- the low–flow channel cross–section should approach the natural stream condition. The bottom width and side slopes should be designed to simulate the natural channel;

- naturally occurring rocks should be placed at selected points for energy dissipation and habitat development;

- the bottom width of the channel should be varied in conjunction with the channel slope to develop pool and riffle areas; and

- for channels with excessive slopes which would otherwise erode and produce sediments, measures such as drop structures, steepened rock–armored sections, and cascade structures should be considered. These structural modifications would provide resistance to high velocity flows and allow the use of stable, moderate gradients upstream and downstream.

### C–9.3.2 Nonstructural Alternatives

Alternatives such as relocating communities off of flood plains, or abandoning structures should be considered as the “best” flood damage reduction measure. Flood plain development and activities should be restricted to those which require minimal flood protection, e.g. greenbelts, parking lots, athletic fields, etc.

## C–9.4 Navigation

### C–9.4.1 Nonstructural Alternatives

An estimation should be made of the long–term requirements for dredged material disposal, and a program implemented to identify suitable disposal areas. This will allow the selection and acquisition of areas at which disposal may be carried out with the least environmental damage. Disposal alternatives should stress habitat development, use as construction material, or other nonwater–related disposal as the “best” methods.

Design specifications which assure adequate water circulation should be incorporated into plans for marinas, docking, and handling facilities. The effects of accidents on the environment should be evaluated for each type of cargo, and transportation and handling regulations applied accordingly.

Water transportation of extremely hazardous or toxic materials should be restricted.

### C–9.4.2 Structural Alternatives

As river commerce increases, the potential for accidents will also increase. Existing navigation hazards should be evaluated with respect to future use, and modified as required.

# TECHNICAL EXHIBIT D
# RESULTS OF FULL–SCALE ANALYSIS WATER TEMPERATURE AND DISSOLVED GAS SATURATION

Data provided in this Attachment were developed from the outputs generated by HEC–5Q and GASSPILL models. Three auxiliary programs were used to process those data in the right format as follows:

– PROCESS program: using data contained in files PERF–TDG.ASC and PERF–WT.ASC calculates maximum, average, and minimum values for the years involved: and stores them in files PERF–TDG.OT1 and PERF–WT.OT1;

– COMP–TDG program: using data from file PERF–TDG.ASC ranks all alternatives based on number of days exceeding 110, 120, and 130 percent saturation; and stores the output in file COMP–TDG.OUT; and

– COMPAR2 program: using data from file PERF–TDG.ASC, calculates the differences in number of days exceeding the given thresholds between the alternatives and the base case.

## WATER TEMPERATURE

### Table D–1. Number of Days Exceeding 17.2 Deg.C Temperature

PROGRAM PERF–WT.BAS OUTF=B:\PERF–WT.ASC

RUN DATE:08–25–1993 TIME:16:26:02

This table contains averages and high and low values for numbers of days exceeding 17.2 degrees C (resistance temperature for fish). Data covered the following 5 years: 1929 (low), 1959 (medium high), 1962 (medium low), 1973 (medium low), and 1974 (high). For each year, 3 different (above average, average, and below average) weather conditions were assumed. For example, under Alternative 1A–29 (Alternative 1a, year 1929), the three rows labelled 29/1, 29/2, and 29/3 refer to each of those three weather conditions and the 1929 flow year. AVER refers to the arithmetic means of the three rows. The 5–year data contains highest numbers of days for all years (Row 1), arithmetic averages (Row 2), and lowest numbers of days (Row 3).

The locations are given in abbreviated form (two characters only because of limited space):
DW = Dworshak
BR = Brownlee
OX = Oxbow
HC = Hells Canyon
LG = Lower Granite
GS = Little Goose
LM = Lower Monumental
IH = Ice Harbor
GC = Grand Coulee
CH = Chief Joseph
WE = Wells
RR = Rocky Reach
RI = Rock Island
WA = Wanapum
PR = Priest Rapids
MNW = McNary (WA)
MNO = McNary (O)
JD = John Day
TD = The Dalles
BO = Bonneville

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 1a–29 (low flow) | | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 62 | 63 | 63 | 81 | 86 | 88 | 88 | 40 | 43 | 57 | 60 | 66 | 69 | 79 | 89 | 90 | 92 | 92 | 93 |
| 29/2 | 0 | 64 | 66 | 68 | 76 | 83 | 84 | 83 | 0 | 6 | 37 | 52 | 56 | 70 | 76 | 84 | 88 | 91 | 93 | 97 |
| 29/3 | 0 | 60 | 62 | 60 | 81 | 81 | 83 | 84 | 52 | 55 | 64 | 72 | 77 | 79 | 82 | 97 | 93 | 94 | 94 | 94 |
| AVER | 0 | 62 | 64 | 64 | 79 | 83 | 85 | 85 | 31 | 35 | 53 | 61 | 66 | 73 | 79 | 90 | 90 | 92 | 93 | 95 |
| Alternative 1a–59 (medium–high flow) | | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 61 | 63 | 67 | 67 | 76 | 81 | 88 | 44 | 49 | 58 | 58 | 65 | 67 | 68 | 74 | 89 | 88 | 88 | 90 |
| 59/2 | 0 | 62 | 67 | 71 | 65 | 74 | 80 | 86 | 5 | 29 | 44 | 49 | 52 | 56 | 58 | 64 | 88 | 74 | 76 | 79 |
| 59/3 | 0 | 60 | 63 | 63 | 71 | 81 | 82 | 83 | 59 | 62 | 66 | 68 | 78 | 80 | 80 | 82 | 86 | 85 | 87 | 88 |
| AVER | 0 | 61 | 64 | 67 | 68 | 77 | 81 | 86 | 36 | 47 | 56 | 58 | 65 | 68 | 69 | 73 | 88 | 82 | 84 | 86 |

**Table D–1. Number of Days Exceeding 17.2 Deg.C Temperature – CONT**

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 1a–62(medium–low flow) | | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 63 | 67 | 67 | 70 | 81 | 88 | 88 | 43 | 45 | 58 | 60 | 66 | 69 | 71 | 87 | 89 | 91 | 92 | 91 |
| 62/2 | 0 | 65 | 67 | 71 | 67 | 79 | 85 | 87 | 0 | 17 | 41 | 52 | 54 | 60 | 63 | 81 | 90 | 89 | 93 | 89 |
| 62/3 | 0 | 61 | 65 | 63 | 75 | 82 | 83 | 84 | 55 | 58 | 65 | 73 | 78 | 79 | 80 | 90 | 93 | 92 | 93 | 91 |
| AVER | 0 | 63 | 66 | 67 | 71 | 81 | 85 | 86 | 33 | 40 | 55 | 62 | 66 | 69 | 71 | 86 | 91 | 91 | 93 | 90 |
| Alternative 1a–73 (medium–low flow) | | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 54 | 57 | 60 | 78 | 84 | 88 | 92 | 42 | 44 | 53 | 58 | 60 | 68 | 69 | 87 | 94 | 93 | 93 | 95 |
| 73/2 | 0 | 57 | 57 | 60 | 68 | 79 | 90 | 94 | 0 | 7 | 25 | 47 | 52 | 61 | 64 | 83 | 97 | 93 | 94 | 101 |
| 73/3 | 0 | 54 | 57 | 57 | 82 | 92 | 92 | 92 | 54 | 56 | 62 | 63 | 70 | 78 | 80 | 94 | 94 | 94 | 94 | 94 |
| AVER | 0 | 55 | 57 | 59 | 76 | 85 | 90 | 93 | 32 | 36 | 47 | 56 | 61 | 69 | 71 | 88 | 95 | 93 | 94 | 97 |
| Alternative 1a–74 (high flow) | | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 75 | 77 | 80 | 81 | 81 | 85 | 59 | 50 | 55 | 58 | 61 | 62 | 65 | 66 | 72 | 89 | 86 | 86 | 89 |
| 74/2 | 0 | 77 | 79 | 84 | 72 | 80 | 84 | 57 | 26 | 43 | 46 | 51 | 51 | 53 | 54 | 66 | 88 | 79 | 80 | 82 |
| 74/3 | 0 | 75 | 79 | 82 | 83 | 82 | 82 | 55 | 62 | 66 | 71 | 72 | 72 | 77 | 79 | 81 | 84 | 82 | 82 | 85 |
| AVER | 0 | 76 | 78 | 82 | 79 | 81 | 84 | 57 | 46 | 55 | 58 | 61 | 62 | 65 | 66 | 73 | 87 | 82 | 83 | 85 |
| 5 YEAR DATA: | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 83 | 92 | 92 | 94 | 62 | 66 | 71 | 73 | 78 | 80 | 82 | 97 | 97 | 94 | 94 | 101 |
| AVER | 0 | 63 | 66 | 68 | 74 | 81 | 85 | 81 | 35 | 42 | 54 | 60 | 64 | 69 | 71 | 82 | 90 | 88 | 89 | 91 |
| LOW | 0 | 54 | 57 | 57 | 65 | 74 | 80 | 55 | 0 | 6 | 25 | 47 | 51 | 53 | 54 | 64 | 84 | 74 | 76 | 79 |

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 1b–29 | | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 62 | 63 | 63 | 64 | 78 | 85 | 87 | 40 | 43 | 54 | 60 | 67 | 70 | 75 | 87 | 89 | 92 | 92 | 92 |
| 29/2 | 0 | 64 | 66 | 68 | 65 | 76 | 83 | 86 | 0 | 6 | 32 | 53 | 57 | 63 | 69 | 83 | 90 | 92 | 93 | 99 |
| 29/3 | 0 | 60 | 62 | 60 | 70 | 81 | 82 | 84 | 51 | 54 | 63 | 73 | 78 | 79 | 82 | 97 | 93 | 94 | 94 | 94 |
| AVER | 0 | 62 | 64 | 64 | 66 | 78 | 83 | 86 | 30 | 34 | 50 | 62 | 67 | 71 | 75 | 89 | 91 | 93 | 93 | 95 |
| Alternative 1b–59 | | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 61 | 63 | 67 | 67 | 76 | 81 | 88 | 44 | 49 | 56 | 58 | 61 | 67 | 68 | 74 | 89 | 88 | 88 | 91 |
| 59/2 | 0 | 62 | 67 | 71 | 65 | 74 | 80 | 85 | 6 | 30 | 43 | 48 | 51 | 55 | 58 | 64 | 87 | 74 | 77 | 80 |
| 59/3 | 0 | 60 | 63 | 63 | 71 | 81 | 82 | 83 | 60 | 62 | 65 | 69 | 76 | 80 | 80 | 82 | 85 | 84 | 88 | 89 |
| AVER | 0 | 61 | 64 | 67 | 68 | 77 | 81 | 85 | 37 | 47 | 55 | 58 | 63 | 67 | 69 | 73 | 87 | 82 | 84 | 87 |
| Alternative 1b–62 | | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 63 | 67 | 67 | 69 | 80 | 88 | 88 | 43 | 46 | 57 | 60 | 66 | 69 | 70 | 87 | 89 | 92 | 92 | 92 |
| 62/2 | 0 | 65 | 67 | 71 | 67 | 78 | 84 | 86 | 0 | 18 | 40 | 51 | 53 | 60 | 62 | 79 | 90 | 90 | 93 | 94 |
| 62/3 | 0 | 61 | 65 | 63 | 73 | 82 | 83 | 84 | 55 | 59 | 64 | 71 | 78 | 79 | 80 | 89 | 93 | 93 | 94 | 94 |
| AVER | 0 | 63 | 66 | 67 | 70 | 80 | 85 | 86 | 33 | 41 | 54 | 61 | 66 | 69 | 71 | 85 | 91 | 92 | 93 | 93 |
| Alternative 1b–73 | | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 54 | 57 | 60 | 63 | 77 | 81 | 88 | 43 | 44 | 53 | 58 | 59 | 67 | 68 | 87 | 92 | 93 | 93 | 95 |
| 73/2 | 0 | 57 | 57 | 60 | 62 | 72 | 81 | 88 | 0 | 9 | 27 | 48 | 51 | 60 | 64 | 83 | 93 | 95 | 96 | 100 |
| 73/3 | 0 | 54 | 57 | 57 | 64 | 79 | 85 | 88 | 54 | 57 | 63 | 63 | 65 | 78 | 79 | 91 | 93 | 94 | 94 | 94 |
| AVER | 0 | 55 | 57 | 59 | 63 | 76 | 82 | 88 | 32 | 37 | 48 | 56 | 58 | 68 | 70 | 87 | 93 | 94 | 94 | 96 |
| Alternative 1b–74 | | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 75 | 77 | 80 | 81 | 81 | 85 | 88 | 50 | 54 | 58 | 59 | 60 | 61 | 61 | 72 | 89 | 86 | 86 | 89 |
| 74/2 | 0 | 77 | 79 | 84 | 72 | 80 | 84 | 86 | 24 | 40 | 45 | 49 | 50 | 52 | 53 | 66 | 88 | 79 | 80 | 82 |
| 74/3 | 0 | 75 | 79 | 82 | 83 | 82 | 82 | 83 | 62 | 65 | 69 | 70 | 69 | 70 | 76 | 81 | 84 | 82 | 82 | 85 |
| AVER | 0 | 76 | 78 | 82 | 79 | 81 | 84 | 86 | 45 | 53 | 57 | 59 | 60 | 61 | 63 | 73 | 87 | 82 | 83 | 85 |

### Table D–1. Number of Days Exceeding 17.2 Deg.C Temperature – CONT

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 YEAR | DATA: | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 83 | 82 | 88 | 88 | 62 | 65 | 69 | 73 | 78 | 80 | 82 | 97 | 93 | 95 | 96 | 100 |
| AVER | 0 | 63 | 66 | 68 | 69 | 78 | 83 | 86 | 35 | 42 | 53 | 59 | 63 | 67 | 70 | 81 | 90 | 89 | 89 | 91 |
| LOW | 0 | 54 | 57 | 57 | 62 | 72 | 80 | 83 | 0 | 6 | 27 | 48 | 50 | 52 | 53 | 64 | 84 | 74 | 77 | 80 |
| Alternative | 2c−29 | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 60 | 62 | 63 | 65 | 76 | 81 | 86 | 41 | 43 | 58 | 68 | 69 | 71 | 71 | 81 | 87 | 90 | 91 | 90 |
| 29/2 | 0 | 62 | 62 | 68 | 62 | 69 | 75 | 82 | 0 | 6 | 38 | 54 | 57 | 61 | 63 | 71 | 87 | 86 | 88 | 88 |
| 29/3 | 0 | 58 | 61 | 59 | 74 | 81 | 82 | 84 | 51 | 54 | 64 | 79 | 79 | 79 | 80 | 83 | 87 | 90 | 90 | 89 |
| AVER | 0 | 60 | 62 | 63 | 67 | 75 | 79 | 84 | 31 | 34 | 53 | 67 | 68 | 70 | 71 | 78 | 87 | 89 | 90 | 89 |
| Alternative | 2c−59 | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 62 | 63 | 66 | 80 | 84 | 88 | 89 | 43 | 49 | 57 | 58 | 64 | 67 | 68 | 74 | 88 | 87 | 88 | 89 |
| 59/2 | 0 | 64 | 67 | 71 | 76 | 83 | 85 | 87 | 5 | 29 | 43 | 49 | 52 | 56 | 58 | 64 | 87 | 74 | 75 | 78 |
| 59/3 | 0 | 62 | 63 | 62 | 81 | 82 | 83 | 84 | 59 | 62 | 65 | 69 | 78 | 80 | 80 | 82 | 89 | 85 | 87 | 88 |
| AVER | 0 | 63 | 64 | 66 | 79 | 83 | 85 | 87 | 36 | 47 | 55 | 59 | 65 | 68 | 69 | 73 | 88 | 82 | 83 | 85 |
| Alternative | 2c−62 | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 62 | 64 | 67 | 83 | 87 | 89 | 89 | 43 | 47 | 58 | 60 | 60 | 68 | 69 | 84 | 90 | 91 | 92 | 91 |
| 62/2 | 0 | 65 | 69 | 73 | 80 | 84 | 85 | 87 | 0 | 15 | 41 | 49 | 51 | 59 | 61 | 79 | 90 | 89 | 92 | 89 |
| 62/3 | 0 | 63 | 63 | 62 | 81 | 82 | 83 | 86 | 55 | 59 | 64 | 66 | 73 | 78 | 79 | 88 | 93 | 92 | 93 | 89 |
| AVER | 0 | 63 | 65 | 67 | 81 | 84 | 86 | 87 | 33 | 40 | 54 | 58 | 61 | 68 | 70 | 84 | 91 | 91 | 92 | 90 |
| Alternative | 2c−73 | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 62 | 62 | 64 | 81 | 88 | 88 | 90 | 42 | 43 | 54 | 59 | 65 | 70 | 72 | 84 | 93 | 91 | 92 | 91 |
| 73/2 | 0 | 62 | 64 | 68 | 82 | 86 | 90 | 92 | 0 | 6 | 29 | 48 | 56 | 62 | 64 | 76 | 93 | 93 | 94 | 92 |
| 73/3 | 0 | 62 | 62 | 60 | 79 | 83 | 90 | 92 | 52 | 55 | 63 | 71 | 74 | 79 | 80 | 87 | 93 | 93 | 94 | 91 |
| AVER | 0 | 62 | 63 | 64 | 81 | 86 | 89 | 91 | 31 | 35 | 49 | 59 | 65 | 70 | 72 | 82 | 93 | 92 | 93 | 91 |
| Alternative | 2c−74 | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 75 | 77 | 80 | 83 | 85 | 85 | 88 | 50 | 52 | 57 | 60 | 62 | 67 | 67 | 74 | 89 | 86 | 86 | 89 |
| 74/2 | 0 | 77 | 80 | 85 | 80 | 83 | 85 | 87 | 24 | 34 | 44 | 50 | 51 | 53 | 54 | 66 | 88 | 79 | 80 | 83 |
| 74/3 | 0 | 76 | 80 | 82 | 83 | 82 | 82 | 84 | 62 | 63 | 66 | 72 | 72 | 78 | 80 | 82 | 84 | 82 | 83 | 85 |
| AVER | 0 | 76 | 79 | 82 | 82 | 83 | 84 | 86 | 45 | 50 | 56 | 61 | 62 | 66 | 67 | 74 | 87 | 82 | 83 | 86 |
| 5 YEAR | DATA | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 80 | 85 | 83 | 88 | 90 | 92 | 62 | 63 | 66 | 79 | 79 | 80 | 80 | 88 | 93 | 93 | 94 | 92 |
| AVE | 0 | 65 | 67 | 69 | 78 | 82 | 85 | 87 | 35 | 41 | 53 | 61 | 64 | 69 | 70 | 78 | 89 | 87 | 88 | 88 |
| LOW | 0 | 58 | 61 | 59 | 62 | 69 | 75 | 82 | 0 | 6 | 29 | 48 | 51 | 53 | 54 | 64 | 84 | 74 | 75 | 78 |
| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
| Alternative | 2d−29 | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 51 | 54 | 63 | 82 | 85 | 89 | 93 | 45 | 50 | 59 | 64 | 67 | 73 | 77 | 84 | 92 | 93 | 93 | 93 |
| 29/2 | 0 | 53 | 57 | 62 | 79 | 85 | 91 | 93 | 34 | 40 | 47 | 51 | 53 | 70 | 72 | 87 | 93 | 91 | 94 | 94 |
| 29/3 | 0 | 51 | 52 | 64 | 84 | 89 | 91 | 92 | 55 | 58 | 70 | 72 | 73 | 78 | 81 | 92 | 93 | 93 | 94 | 93 |
| AVER | 0 | 52 | 54 | 63 | 82 | 86 | 90 | 93 | 45 | 49 | 59 | 62 | 64 | 74 | 77 | 88 | 93 | 92 | 94 | 93 |
| Alternative | 2d−59 | | | | | | | | | | | | | | | | | | | |
| 59/1 | 18 | 56 | 58 | 66 | 76 | 83 | 83 | 89 | 50 | 54 | 60 | 62 | 66 | 66 | 67 | 76 | 92 | 86 | 87 | 87 |
| 59/2 | 17 | 58 | 62 | 66 | 73 | 81 | 85 | 91 | 38 | 41 | 48 | 55 | 63 | 66 | 67 | 73 | 92 | 85 | 87 | 87 |
| 59/3 | 18 | 55 | 57 | 68 | 78 | 87 | 88 | 92 | 59 | 64 | 70 | 73 | 73 | 75 | 75 | 82 | 93 | 90 | 91 | 91 |
| AVER | 18 | 56 | 59 | 67 | 76 | 84 | 85 | 91 | 49 | 53 | 59 | 63 | 67 | 69 | 70 | 77 | 92 | 87 | 88 | 88 |

## Table D-1. Number of Days Exceeding 17.2 Deg.C Temperature – CONT

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative | 2d–62 | | | | | | | | | | | | | | | | | | | |
| 62/1 | 26 | 57 | 59 | 68 | 71 | 77 | 82 | 93 | 47 | 51 | 58 | 61 | 63 | 71 | 75 | 84 | 93 | 93 | 94 | 93 |
| 62/2 | 26 | 59 | 63 | 67 | 67 | 78 | 86 | 94 | 35 | 40 | 44 | 51 | 55 | 66 | 70 | 87 | 92 | 92 | 94 | 94 |
| 62/3 | 26 | 56 | 58 | 69 | 73 | 80 | 84 | 93 | 59 | 62 | 69 | 71 | 72 | 73 | 77 | 91 | 93 | 93 | 94 | 94 |
| AVER | 26 | 57 | 60 | 68 | 70 | 78 | 84 | 93 | 47 | 51 | 57 | 61 | 63 | 70 | 74 | 87 | 93 | 93 | 94 | 94 |
| Alternative | 2d–73 | | | | | | | | | | | | | | | | | | | |
| 73/1 | 2 | 54 | 57 | 63 | 83 | 87 | 89 | 92 | 40 | 48 | 57 | 66 | 69 | 76 | 78 | 84 | 93 | 93 | 94 | 93 |
| 73/2 | 2 | 57 | 60 | 66 | 80 | 89 | 92 | 93 | 32 | 40 | 48 | 56 | 58 | 73 | 74 | 87 | 94 | 94 | 96 | 96 |
| 73/3 | 2 | 54 | 56 | 66 | 87 | 90 | 90 | 92 | 54 | 54 | 66 | 70 | 73 | 81 | 83 | 92 | 93 | 94 | 94 | 94 |
| AVER | 2 | 55 | 58 | 65 | 83 | 89 | 90 | 92 | 42 | 47 | 57 | 64 | 67 | 77 | 78 | 88 | 93 | 94 | 95 | 94 |
| Alternative | 2d–74 | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 79 | 83 | 85 | 84 | 87 | 89 | 90 | 53 | 60 | 63 | 65 | 65 | 67 | 69 | 76 | 91 | 87 | 87 | 87 |
| 74/2 | 0 | 81 | 84 | 87 | 82 | 85 | 87 | 90 | 40 | 44 | 47 | 52 | 55 | 64 | 65 | 74 | 88 | 82 | 82 | 84 |
| 74/3 | 0 | 78 | 82 | 86 | 87 | 88 | 87 | 90 | 62 | 69 | 73 | 74 | 75 | 75 | 75 | 79 | 92 | 88 | 88 | 89 |
| AVER | 0 | 79 | 83 | 86 | 84 | 87 | 88 | 90 | 52 | 58 | 61 | 64 | 65 | 69 | 70 | 76 | 90 | 86 | 86 | 87 |
| 5 YEAR | DATA | | | | | | | | | | | | | | | | | | | |
| HIGH | 26 | 81 | 84 | 87 | 87 | 90 | 92 | 94 | 62 | 69 | 73 | 74 | 75 | 81 | 83 | 92 | 94 | 94 | 96 | 96 |
| AVE | 9 | 60 | 63 | 70 | 79 | 85 | 88 | 92 | 47 | 52 | 59 | 63 | 65 | 72 | 74 | 83 | 92 | 90 | 91 | 91 |
| LOW | 0 | 51 | 52 | 62 | 67 | 77 | 82 | 89 | 32 | 40 | 44 | 51 | 53 | 64 | 65 | 73 | 88 | 82 | 82 | 84 |

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative | 4c–29 | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 59 | 59 | 63 | 81 | 86 | 88 | 91 | 42 | 49 | 57 | 63 | 64 | 70 | 73 | 81 | 92 | 92 | 93 | 93 |
| 29/2 | 0 | 62 | 64 | 65 | 79 | 83 | 85 | 90 | 34 | 39 | 45 | 53 | 56 | 69 | 71 | 86 | 93 | 93 | 96 | 97 |
| 29/3 | 0 | 58 | 60 | 66 | 84 | 87 | 89 | 91 | 56 | 57 | 70 | 73 | 73 | 74 | 77 | 91 | 92 | 93 | 94 | 93 |
| AVER | 0 | 59 | 61 | 64 | 81 | 85 | 87 | 91 | 44 | 48 | 57 | 63 | 64 | 71 | 74 | 86 | 92 | 93 | 94 | 94 |
| Alternative | 4c–59 | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 63 | 64 | 67 | 76 | 85 | 86 | 88 | 50 | 53 | 60 | 64 | 67 | 70 | 72 | 80 | 92 | 88 | 88 | 89 |
| 59/2 | 0 | 64 | 66 | 70 | 78 | 81 | 83 | 89 | 38 | 41 | 45 | 56 | 63 | 69 | 70 | 76 | 92 | 89 | 89 | 89 |
| 59/3 | 0 | 62 | 64 | 68 | 82 | 88 | 90 | 91 | 59 | 63 | 70 | 74 | 75 | 78 | 80 | 84 | 92 | 91 | 92 | 92 |
| AVER | 0 | 63 | 65 | 68 | 79 | 85 | 86 | 89 | 49 | 52 | 58 | 65 | 68 | 72 | 74 | 80 | 92 | 89 | 90 | 90 |
| Alternative | 4c–62 | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 63 | 65 | 68 | 82 | 86 | 88 | 91 | 49 | 53 | 60 | 65 | 67 | 73 | 75 | 83 | 92 | 91 | 91 | 91 |
| 62/2 | 0 | 66 | 67 | 71 | 80 | 84 | 87 | 91 | 36 | 41 | 46 | 52 | 57 | 69 | 71 | 82 | 93 | 91 | 92 | 93 |
| 62/3 | 0 | 63 | 65 | 69 | 86 | 89 | 90 | 91 | 61 | 64 | 71 | 73 | 73 | 75 | 77 | 89 | 92 | 93 | 94 | 93 |
| AVER | 0 | 64 | 66 | 69 | 83 | 86 | 88 | 91 | 49 | 53 | 59 | 63 | 66 | 72 | 74 | 85 | 92 | 92 | 92 | 92 |
| Alternative | 4c–73 | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 61 | 63 | 63 | 86 | 90 | 91 | 93 | 42 | 49 | 54 | 61 | 63 | 71 | 76 | 85 | 94 | 94 | 94 | 94 |
| 73/2 | 0 | 64 | 65 | 68 | 82 | 91 | 93 | 94 | 34 | 40 | 44 | 50 | 54 | 70 | 73 | 88 | 96 | 97 | 98 | 98 |
| 73/3 | 0 | 60 | 62 | 67 | 90 | 91 | 91 | 92 | 57 | 59 | 67 | 72 | 72 | 73 | 76 | 92 | 94 | 94 | 95 | 94 |
| AVER | 0 | 62 | 63 | 66 | 86 | 91 | 92 | 93 | 44 | 49 | 55 | 61 | 63 | 71 | 75 | 88 | 95 | 95 | 96 | 95 |
| Alternative | 4c–74 | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 79 | 82 | 86 | 84 | 88 | 89 | 90 | 54 | 59 | 65 | 68 | 68 | 71 | 72 | 78 | 91 | 87 | 88 | 88 |
| 74/2 | 0 | 80 | 83 | 87 | 83 | 85 | 88 | 90 | 41 | 45 | 49 | 57 | 60 | 66 | 67 | 75 | 88 | 83 | 84 | 84 |
| 74/3 | 0 | 78 | 79 | 86 | 89 | 88 | 88 | 90 | 63 | 69 | 75 | 75 | 75 | 76 | 76 | 80 | 92 | 90 | 90 | 90 |
| AVER | 0 | 79 | 81 | 86 | 85 | 87 | 88 | 90 | 53 | 58 | 63 | 67 | 68 | 71 | 72 | 78 | 90 | 87 | 87 | 87 |

**Table D–1. Number of Days Exceeding 17.2 Deg.C Temperature – CONT**

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 YEAR DATA | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 80 | 83 | 87 | 90 | 91 | 93 | 94 | 63 | 69 | 75 | 75 | 75 | 78 | 80 | 92 | 96 | 97 | 98 | 98 |
| AVE | 0 | 65 | 67 | 71 | 83 | 87 | 88 | 91 | 48 | 52 | 58 | 64 | 66 | 72 | 74 | 83 | 92 | 91 | 92 | 92 |
| LOW | 0 | 58 | 59 | 63 | 76 | 81 | 83 | 88 | 34 | 39 | 44 | 50 | 54 | 66 | 67 | 75 | 88 | 83 | 84 | 84 |
| Alternative 5b–29 | | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 59 | 61 | 62 | 58 | 62 | 65 | 74 | 31 | 33 | 44 | 70 | 74 | 79 | 80 | 88 | 87 | 91 | 92 | 91 |
| 29/2 | 0 | 61 | 60 | 65 | 58 | 63 | 66 | 76 | 0 | 0 | 25 | 41 | 47 | 72 | 74 | 84 | 85 | 82 | 86 | 87 |
| 29/3 | 0 | 57 | 60 | 58 | 57 | 60 | 64 | 83 | 42 | 39 | 57 | 79 | 81 | 87 | 93 | 96 | 84 | 90 | 91 | 89 |
| AVER | 0 | 59 | 60 | 62 | 58 | 62 | 65 | 78 | 24 | 24 | 42 | 63 | 67 | 79 | 82 | 89 | 85 | 88 | 90 | 89 |
| Alternative 5b–59 | | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 62 | 63 | 65 | 62 | 68 | 77 | 82 | 44 | 50 | 57 | 58 | 59 | 65 | 66 | 73 | 87 | 89 | 89 | 89 |
| 59/2 | 0 | 63 | 66 | 69 | 61 | 64 | 69 | 82 | 4 | 29 | 43 | 47 | 49 | 53 | 56 | 63 | 86 | 75 | 76 | 78 |
| 59/3 | 0 | 62 | 62 | 61 | 71 | 84 | 84 | 84 | 59 | 62 | 65 | 67 | 67 | 77 | 79 | 81 | 83 | 86 | 88 | 88 |
| AVER | 0 | 62 | 64 | 65 | 65 | 72 | 77 | 83 | 36 | 47 | 55 | 57 | 58 | 65 | 67 | 72 | 85 | 83 | 84 | 85 |
| Alternative 5b–62 | | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 63 | 63 | 66 | 58 | 61 | 67 | 77 | 41 | 43 | 44 | 57 | 57 | 68 | 80 | 90 | 87 | 92 | 92 | 91 |
| 62/2 | 0 | 65 | 67 | 71 | 58 | 62 | 67 | 77 | 0 | 7 | 19 | 39 | 46 | 71 | 74 | 85 | 86 | 84 | 86 | 87 |
| 62/3 | 0 | 62 | 62 | 61 | 57 | 61 | 66 | 84 | 52 | 54 | 57 | 61 | 61 | 78 | 84 | 97 | 83 | 91 | 92 | 89 |
| AVER | 0 | 63 | 64 | 66 | 58 | 61 | 67 | 79 | 31 | 35 | 40 | 52 | 55 | 72 | 79 | 91 | 85 | 89 | 90 | 89 |
| Alternative 5b–73 | | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 62 | 62 | 62 | 60 | 63 | 66 | 76 | 37 | 41 | 46 | 59 | 65 | 70 | 74 | 86 | 95 | 93 | 93 | 92 |
| 73/2 | 0 | 62 | 63 | 66 | 60 | 63 | 67 | 76 | 0 | 4 | 19 | 49 | 52 | 63 | 65 | 83 | 87 | 93 | 94 | 93 |
| 73/3 | 0 | 61 | 61 | 59 | 57 | 61 | 66 | 84 | 50 | 52 | 57 | 71 | 75 | 80 | 82 | 97 | 92 | 95 | 95 | 93 |
| AVER | 0 | 62 | 62 | 62 | 59 | 62 | 66 | 79 | 29 | 32 | 41 | 60 | 64 | 71 | 74 | 89 | 91 | 94 | 94 | 93 |
| Alternative 5b–74 | | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 75 | 77 | 80 | 64 | 66 | 71 | 81 | 50 | 52 | 52 | 54 | 55 | 59 | 58 | 71 | 88 | 86 | 86 | 87 |
| 74/2 | 0 | 77 | 79 | 84 | 62 | 62 | 67 | 81 | 25 | 35 | 34 | 42 | 42 | 48 | 51 | 65 | 87 | 80 | 81 | 83 |
| 74/3 | 0 | 75 | 79 | 82 | 70 | 85 | 85 | 84 | 62 | 63 | 64 | 64 | 64 | 64 | 64 | 79 | 84 | 82 | 82 | 85 |
| AVER | 0 | 76 | 78 | 82 | 65 | 71 | 74 | 82 | 46 | 50 | 50 | 53 | 54 | 57 | 58 | 72 | 86 | 83 | 83 | 85 |
| 5 YEAR DATA | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 71 | 85 | 85 | 84 | 62 | 63 | 65 | 79 | 81 | 87 | 93 | 97 | 95 | 95 | 95 | 93 |
| AVE | 0 | 64 | 66 | 67 | 61 | 66 | 70 | 80 | 33 | 38 | 46 | 57 | 60 | 69 | 72 | 83 | 87 | 87 | 88 | 88 |
| LOW | 0 | 57 | 60 | 58 | 57 | 60 | 64 | 74 | 0 | 0 | 19 | 39 | 42 | 48 | 51 | 63 | 83 | 75 | 76 | 78 |
| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
| Alternative 5c–29 | | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 59 | 59 | 63 | 71 | 72 | 72 | 74 | 30 | 31 | 52 | 70 | 73 | 83 | 85 | 88 | 81 | 91 | 93 | 94 |
| 29/2 | 0 | 62 | 64 | 65 | 68 | 69 | 70 | 70 | 21 | 33 | 53 | 68 | 70 | 75 | 81 | 94 | 76 | 92 | 93 | 95 |
| 29/3 | 0 | 58 | 60 | 66 | 73 | 78 | 81 | 83 | 41 | 42 | 60 | 78 | 81 | 85 | 89 | 98 | 88 | 94 | 94 | 96 |
| AVER | 0 | 60 | 61 | 65 | 71 | 73 | 74 | 76 | 31 | 35 | 55 | 72 | 75 | 81 | 85 | 93 | 82 | 92 | 93 | 95 |
| Alternative 5c–59 | | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 63 | 64 | 67 | 71 | 72 | 72 | 75 | 49 | 53 | 59 | 62 | 63 | 66 | 68 | 83 | 81 | 88 | 89 | 91 |
| 59/2 | 0 | 65 | 66 | 70 | 72 | 73 | 73 | 73 | 37 | 40 | 44 | 50 | 52 | 59 | 64 | 85 | 79 | 90 | 90 | 91 |
| 59/3 | 0 | 62 | 64 | 68 | 78 | 79 | 81 | 82 | 60 | 64 | 71 | 73 | 73 | 73 | 74 | 88 | 88 | 92 | 92 | 95 |
| AVER | 0 | 63 | 65 | 68 | 74 | 75 | 75 | 77 | 49 | 52 | 58 | 62 | 63 | 66 | 69 | 85 | 83 | 90 | 90 | 92 |

Table D–1. Number of Days Exceeding 17.2 Deg.C Temperature – CONT

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 5c−62 | | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 63 | 65 | 68 | 71 | 72 | 73 | 76 | 42 | 47 | 50 | 58 | 59 | 76 | 80 | 89 | 82 | 92 | 94 | 94 |
| 62/2 | 0 | 66 | 68 | 71 | 71 | 71 | 71 | 72 | 31 | 38 | 44 | 50 | 54 | 73 | 78 | 96 | 81 | 92 | 93 | 95 |
| 62/3 | 0 | 63 | 65 | 69 | 78 | 82 | 82 | 82 | 54 | 53 | 59 | 67 | 69 | 84 | 90 | 99 | 89 | 94 | 95 | 96 |
| AVER | 0 | 64 | 66 | 69 | 73 | 75 | 75 | 77 | 42 | 46 | 51 | 58 | 61 | 78 | 83 | 95 | 84 | 93 | 94 | 95 |
| Alternative 5c−73 | | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 61 | 63 | 63 | 72 | 74 | 79 | 80 | 35 | 40 | 54 | 63 | 67 | 76 | 79 | 87 | 83 | 93 | 94 | 95 |
| 73/2 | 0 | 64 | 65 | 68 | 70 | 74 | 75 | 78 | 28 | 38 | 47 | 54 | 57 | 71 | 79 | 94 | 87 | 96 | 96 | 98 |
| 73/3 | 0 | 60 | 61 | 67 | 79 | 83 | 86 | 87 | 46 | 50 | 61 | 67 | 69 | 87 | 88 | 96 | 90 | 96 | 96 | 98 |
| AVER | 0 | 62 | 63 | 66 | 74 | 77 | 80 | 82 | 36 | 43 | 54 | 61 | 64 | 78 | 82 | 92 | 87 | 95 | 95 | 97 |
| Alternative 5c−74 | | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 79 | 82 | 86 | 73 | 75 | 75 | 77 | 52 | 55 | 56 | 62 | 63 | 68 | 70 | 79 | 83 | 88 | 89 | 89 |
| 74/2 | 0 | 80 | 83 | 87 | 76 | 77 | 79 | 76 | 39 | 43 | 44 | 48 | 49 | 58 | 59 | 75 | 83 | 84 | 85 | 85 |
| 74/3 | 0 | 78 | 79 | 86 | 80 | 81 | 82 | 80 | 63 | 64 | 69 | 72 | 72 | 74 | 75 | 80 | 86 | 88 | 89 | 91 |
| AVER | 0 | 79 | 81 | 86 | 76 | 78 | 79 | 78 | 51 | 54 | 56 | 61 | 61 | 67 | 68 | 78 | 84 | 87 | 88 | 88 |
| 5 YEAR DATA | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 80 | 83 | 87 | 80 | 83 | 86 | 87 | 63 | 64 | 71 | 78 | 81 | 87 | 90 | 99 | 90 | 96 | 96 | 98 |
| AVE | 0 | 66 | 67 | 71 | 74 | 75 | 77 | 78 | 42 | 46 | 55 | 63 | 65 | 74 | 77 | 89 | 84 | 91 | 92 | 94 |
| LOW | 0 | 58 | 59 | 63 | 68 | 69 | 70 | 70 | 21 | 31 | 44 | 48 | 49 | 58 | 59 | 75 | 76 | 84 | 85 | 85 |

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 6b−29 | | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 59 | 61 | 62 | 63 | 74 | 84 | 88 | 38 | 42 | 60 | 69 | 71 | 72 | 73 | 82 | 90 | 90 | 91 | 91 |
| 29/2 | 0 | 61 | 60 | 65 | 63 | 71 | 81 | 87 | 0 | 4 | 33 | 54 | 56 | 61 | 63 | 73 | 86 | 88 | 90 | 88 |
| 29/3 | 0 | 57 | 60 | 58 | 61 | 81 | 83 | 84 | 50 | 52 | 74 | 80 | 80 | 80 | 81 | 86 | 87 | 92 | 93 | 89 |
| AVER | 0 | 59 | 60 | 62 | 62 | 75 | 83 | 86 | 29 | 33 | 56 | 68 | 69 | 71 | 72 | 80 | 88 | 90 | 91 | 89 |
| Alternative 6b−59 | | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 62 | 63 | 65 | 65 | 75 | 80 | 86 | 44 | 48 | 57 | 58 | 65 | 67 | 68 | 76 | 89 | 88 | 88 | 89 |
| 59/2 | 0 | 63 | 66 | 69 | 63 | 70 | 76 | 84 | 4 | 29 | 43 | 49 | 52 | 57 | 58 | 65 | 88 | 73 | 75 | 79 |
| 59/3 | 0 | 62 | 62 | 61 | 72 | 81 | 83 | 84 | 59 | 62 | 65 | 70 | 78 | 80 | 80 | 82 | 86 | 84 | 86 | 88 |
| AVER | 0 | 62 | 64 | 65 | 67 | 75 | 80 | 85 | 36 | 46 | 55 | 59 | 65 | 68 | 69 | 74 | 88 | 82 | 83 | 85 |
| Alternative 6b−62 | | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 63 | 63 | 66 | 68 | 80 | 88 | 89 | 43 | 48 | 58 | 60 | 60 | 68 | 68 | 83 | 91 | 91 | 92 | 91 |
| 62/2 | 0 | 65 | 67 | 71 | 65 | 76 | 85 | 88 | 0 | 19 | 41 | 50 | 51 | 59 | 62 | 75 | 87 | 89 | 93 | 89 |
| 62/3 | 0 | 62 | 62 | 61 | 76 | 82 | 83 | 85 | 55 | 59 | 64 | 66 | 73 | 78 | 79 | 87 | 94 | 93 | 94 | 90 |
| AVER | 0 | 63 | 64 | 66 | 70 | 79 | 85 | 87 | 33 | 42 | 54 | 59 | 61 | 68 | 70 | 82 | 91 | 91 | 93 | 90 |
| Alternative 6b−73 | | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 62 | 62 | 62 | 64 | 80 | 86 | 91 | 40 | 43 | 54 | 60 | 66 | 71 | 72 | 83 | 96 | 91 | 92 | 91 |
| 73/2 | 0 | 62 | 63 | 66 | 62 | 73 | 82 | 96 | 0 | 6 | 25 | 48 | 56 | 61 | 63 | 75 | 100 | 93 | 94 | 92 |
| 73/3 | 0 | 61 | 61 | 59 | 67 | 84 | 95 | 95 | 52 | 55 | 63 | 72 | 78 | 79 | 81 | 88 | 96 | 93 | 94 | 93 |
| AVER | 0 | 62 | 62 | 62 | 64 | 79 | 88 | 94 | 31 | 35 | 47 | 60 | 67 | 70 | 72 | 82 | 97 | 92 | 93 | 92 |
| Alternative 6b−74 | | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 75 | 77 | 80 | 84 | 85 | 87 | 88 | 50 | 51 | 57 | 60 | 62 | 67 | 67 | 74 | 89 | 86 | 86 | 89 |
| 74/2 | 0 | 77 | 79 | 84 | 74 | 81 | 87 | 88 | 22 | 33 | 44 | 50 | 51 | 54 | 54 | 67 | 88 | 81 | 81 | 84 |
| 74/3 | 0 | 75 | 79 | 82 | 84 | 84 | 83 | 84 | 61 | 62 | 66 | 72 | 73 | 79 | 80 | 82 | 84 | 82 | 83 | 85 |
| AVER | 0 | 76 | 78 | 82 | 81 | 83 | 86 | 87 | 44 | 49 | 56 | 61 | 62 | 67 | 67 | 74 | 87 | 83 | 83 | 86 |

**Table D–1. Number of Days Exceeding 17.2 Deg.C Temperature – CONT**

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 YEAR DATA | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 84 | 85 | 95 | 96 | 61 | 62 | 74 | 80 | 80 | 80 | 81 | 88 | 100 | 93 | 94 | 93 |
| AVE | 0 | 64 | 66 | 67 | 69 | 78 | 84 | 88 | 35 | 41 | 54 | 61 | 65 | 69 | 70 | 79 | 90 | 88 | 89 | 89 |
| LOW | 0 | 57 | 60 | 58 | 61 | 70 | 76 | 84 | 0 | 4 | 25 | 48 | 51 | 54 | 54 | 65 | 84 | 73 | 75 | 79 |
| Alternative 6d–29 | | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 59 | 61 | 62 | 62 | 73 | 81 | 88 | 38 | 42 | 60 | 69 | 71 | 72 | 73 | 82 | 88 | 90 | 91 | 90 |
| 29/2 | 0 | 61 | 60 | 65 | 62 | 70 | 78 | 86 | 0 | 4 | 33 | 54 | 56 | 61 | 63 | 73 | 88 | 86 | 88 | 88 |
| 29/3 | 0 | 57 | 60 | 58 | 60 | 77 | 82 | 83 | 50 | 52 | 74 | 80 | 80 | 80 | 81 | 86 | 87 | 90 | 90 | 89 |
| AVER | 0 | 59 | 60 | 62 | 61 | 73 | 80 | 86 | 29 | 33 | 56 | 68 | 69 | 71 | 72 | 80 | 88 | 89 | 90 | 89 |
| Alternative 6d–59 | | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 62 | 63 | 65 | 65 | 74 | 80 | 84 | 44 | 48 | 57 | 58 | 65 | 67 | 68 | 76 | 88 | 88 | 89 | 89 |
| 59/2 | 0 | 63 | 66 | 69 | 63 | 70 | 75 | 82 | 4 | 29 | 43 | 49 | 52 | 57 | 58 | 65 | 87 | 73 | 76 | 78 |
| 59/3 | 0 | 62 | 62 | 61 | 72 | 81 | 82 | 84 | 59 | 62 | 65 | 70 | 78 | 80 | 80 | 82 | 85 | 84 | 86 | 88 |
| AVER | 0 | 62 | 64 | 65 | 67 | 75 | 79 | 83 | 36 | 46 | 55 | 59 | 65 | 68 | 69 | 74 | 87 | 82 | 84 | 85 |
| Alternative 6d–62 | | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 63 | 63 | 66 | 68 | 77 | 85 | 89 | 43 | 48 | 58 | 60 | 60 | 68 | 68 | 83 | 89 | 91 | 92 | 91 |
| 62/2 | 0 | 65 | 67 | 71 | 65 | 74 | 82 | 87 | 0 | 19 | 41 | 50 | 51 | 59 | 62 | 75 | 89 | 90 | 90 | 88 |
| 62/3 | 0 | 62 | 62 | 61 | 74 | 81 | 83 | 84 | 55 | 59 | 64 | 66 | 73 | 78 | 79 | 87 | 93 | 92 | 93 | 89 |
| AVER | 0 | 63 | 64 | 66 | 69 | 77 | 83 | 87 | 33 | 42 | 54 | 59 | 61 | 68 | 70 | 82 | 90 | 91 | 92 | 89 |
| Alternative 6d–73 | | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 62 | 62 | 62 | 63 | 79 | 82 | 89 | 40 | 43 | 54 | 60 | 66 | 71 | 72 | 83 | 94 | 91 | 92 | 91 |
| 73/2 | 0 | 62 | 63 | 66 | 62 | 72 | 81 | 92 | 0 | 6 | 25 | 48 | 56 | 61 | 63 | 75 | 96 | 93 | 94 | 91 |
| 73/3 | 0 | 61 | 61 | 59 | 67 | 81 | 93 | 93 | 52 | 55 | 63 | 72 | 78 | 79 | 81 | 88 | 94 | 93 | 94 | 93 |
| AVER | 0 | 62 | 62 | 62 | 64 | 77 | 85 | 91 | 31 | 35 | 47 | 60 | 67 | 70 | 72 | 82 | 95 | 92 | 93 | 92 |
| Alternative 6d–74 | | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 75 | 77 | 80 | 83 | 83 | 84 | 88 | 50 | 51 | 57 | 60 | 62 | 67 | 67 | 74 | 89 | 86 | 86 | 89 |
| 74/2 | 0 | 77 | 79 | 84 | 74 | 79 | 83 | 87 | 22 | 33 | 44 | 50 | 51 | 54 | 54 | 67 | 88 | 81 | 81 | 84 |
| 74/3 | 0 | 75 | 79 | 82 | 84 | 83 | 82 | 84 | 61 | 62 | 66 | 72 | 73 | 79 | 80 | 82 | 84 | 82 | 83 | 85 |
| AVER | 0 | 76 | 78 | 82 | 80 | 82 | 83 | 86 | 44 | 49 | 56 | 61 | 62 | 67 | 67 | 74 | 87 | 83 | 83 | 86 |
| 5 YEAR DATA | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 77 | 79 | 84 | 84 | 83 | 93 | 93 | 61 | 62 | 74 | 80 | 80 | 80 | 81 | 88 | 96 | 93 | 94 | 93 |
| AVE | 0 | 64 | 66 | 67 | 68 | 77 | 82 | 87 | 35 | 41 | 54 | 61 | 65 | 69 | 70 | 79 | 89 | 87 | 88 | 88 |
| LOW | 0 | 57 | 60 | 58 | 60 | 70 | 75 | 82 | 0 | 4 | 25 | 48 | 51 | 54 | 54 | 65 | 84 | 73 | 76 | 78 |
| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
| Alternative 9a–29 | | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 73 | 75 | 77 | 80 | 83 | 86 | 88 | 50 | 54 | 60 | 64 | 66 | 75 | 77 | 86 | 91 | 92 | 91 | 93 |
| 29/2 | 0 | 76 | 77 | 80 | 75 | 81 | 83 | 87 | 40 | 44 | 49 | 59 | 65 | 72 | 72 | 81 | 93 | 94 | 94 | 95 |
| 29/3 | 0 | 73 | 75 | 74 | 81 | 84 | 86 | 91 | 57 | 62 | 68 | 74 | 75 | 79 | 80 | 92 | 93 | 92 | 93 | 94 |
| AVER | 0 | 74 | 76 | 77 | 79 | 83 | 85 | 89 | 49 | 53 | 59 | 66 | 69 | 75 | 76 | 86 | 92 | 93 | 93 | 94 |
| Alternative 9a–59 | | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 74 | 75 | 77 | 80 | 85 | 87 | 89 | 50 | 54 | 60 | 65 | 68 | 74 | 75 | 81 | 91 | 90 | 90 | 90 |
| 59/2 | 0 | 77 | 78 | 80 | 80 | 82 | 84 | 86 | 38 | 42 | 45 | 54 | 60 | 69 | 70 | 78 | 92 | 89 | 90 | 91 |
| 59/3 | 0 | 73 | 75 | 74 | 83 | 88 | 89 | 91 | 59 | 64 | 71 | 74 | 75 | 76 | 78 | 86 | 93 | 92 | 92 | 93 |
| AVER | 0 | 75 | 76 | 77 | 81 | 85 | 87 | 89 | 49 | 53 | 59 | 64 | 68 | 73 | 74 | 82 | 92 | 90 | 91 | 91 |

## Table D–1. Number of Days Exceeding 17.2 Deg.C Temperature – CONT

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 9a–62 | | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 75 | 76 | 78 | 82 | 85 | 87 | 89 | 50 | 54 | 62 | 65 | 67 | 72 | 75 | 86 | 91 | 93 | 94 | 94 |
| 62/2 | 0 | 77 | 79 | 81 | 79 | 82 | 84 | 88 | 38 | 43 | 46 | 54 | 60 | 68 | 68 | 88 | 93 | 93 | 94 | 96 |
| 62/3 | 0 | 74 | 75 | 75 | 85 | 87 | 88 | 91 | 59 | 66 | 71 | 73 | 74 | 74 | 75 | 92 | 93 | 93 | 93 | 95 |
| AVER | 0 | 75 | 77 | 78 | 82 | 85 | 86 | 89 | 49 | 54 | 60 | 64 | 67 | 71 | 73 | 89 | 92 | 93 | 94 | 95 |
| Alternative 9a–73 | | | | | | | | | | | | | | | | | | | | |
| 73/1 | 55 | 76 | 77 | 77 | 85 | 88 | 89 | 90 | 50 | 54 | 61 | 66 | 68 | 75 | 77 | 87 | 92 | 92 | 91 | 92 |
| 73/2 | 46 | 78 | 79 | 80 | 84 | 85 | 87 | 89 | 40 | 44 | 49 | 57 | 60 | 72 | 74 | 81 | 93 | 94 | 94 | 95 |
| 73/3 | 70 | 77 | 77 | 77 | 86 | 88 | 88 | 92 | 57 | 62 | 71 | 74 | 74 | 78 | 80 | 91 | 93 | 92 | 93 | 94 |
| AVER | 57 | 77 | 78 | 78 | 85 | 87 | 88 | 90 | 49 | 53 | 60 | 66 | 67 | 75 | 77 | 86 | 93 | 93 | 93 | 94 |
| Alternative 9a–74 | | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 88 | 89 | 90 | 86 | 87 | 88 | 90 | 52 | 56 | 60 | 67 | 68 | 70 | 71 | 79 | 90 | 89 | 88 | 88 |
| 74/2 | 0 | 89 | 90 | 92 | 84 | 84 | 85 | 87 | 40 | 44 | 46 | 54 | 59 | 64 | 68 | 74 | 89 | 86 | 86 | 86 |
| 74/3 | 0 | 88 | 90 | 92 | 89 | 90 | 89 | 91 | 59 | 65 | 73 | 75 | 76 | 76 | 76 | 81 | 92 | 90 | 90 | 91 |
| AVER | 0 | 88 | 90 | 91 | 86 | 87 | 87 | 89 | 50 | 55 | 60 | 65 | 68 | 70 | 72 | 78 | 90 | 88 | 88 | 88 |
| 5 YEAR DATA | | | | | | | | | | | | | | | | | | | | |
| HIGH | 70 | 89 | 90 | 92 | 89 | 90 | 89 | 92 | 59 | 66 | 73 | 75 | 76 | 79 | 80 | 92 | 93 | 94 | 94 | 96 |
| AVE | 11 | 78 | 79 | 80 | 83 | 85 | 87 | 89 | 49 | 54 | 59 | 65 | 68 | 73 | 74 | 84 | 92 | 91 | 92 | 92 |
| LOW | 0 | 73 | 75 | 74 | 75 | 81 | 83 | 86 | 38 | 42 | 45 | 54 | 59 | 64 | 68 | 74 | 89 | 86 | 86 | 86 |

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 9b–29 | | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 60 | 62 | 69 | 86 | 87 | 88 | 91 | 50 | 53 | 60 | 65 | 68 | 73 | 76 | 84 | 93 | 92 | 91 | 92 |
| 29/2 | 0 | 61 | 65 | 68 | 82 | 86 | 90 | 93 | 37 | 41 | 46 | 54 | 60 | 70 | 71 | 87 | 93 | 93 | 94 | 96 |
| 29/3 | 0 | 60 | 62 | 68 | 85 | 89 | 89 | 91 | 61 | 64 | 71 | 73 | 74 | 75 | 78 | 90 | 92 | 92 | 93 | 93 |
| AVER | 0 | 60 | 63 | 68 | 84 | 87 | 89 | 92 | 49 | 53 | 59 | 64 | 67 | 73 | 75 | 87 | 93 | 92 | 93 | 94 |
| Alternative 9b–59 | | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 62 | 66 | 72 | 83 | 86 | 87 | 88 | 51 | 54 | 59 | 64 | 66 | 70 | 71 | 80 | 92 | 88 | 88 | 89 |
| 59/2 | 0 | 66 | 71 | 76 | 81 | 83 | 85 | 88 | 38 | 42 | 44 | 52 | 59 | 67 | 69 | 76 | 93 | 89 | 89 | 90 |
| 59/3 | 0 | 62 | 68 | 70 | 85 | 87 | 88 | 91 | 60 | 64 | 70 | 74 | 74 | 76 | 77 | 86 | 92 | 91 | 92 | 92 |
| AVER | 0 | 63 | 68 | 73 | 83 | 85 | 87 | 89 | 50 | 53 | 58 | 63 | 66 | 71 | 72 | 81 | 92 | 89 | 90 | 90 |
| Alternative 9b–62 | | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 65 | 67 | 74 | 87 | 88 | 88 | 90 | 50 | 54 | 60 | 64 | 67 | 72 | 73 | 84 | 93 | 93 | 92 | 93 |
| 62/2 | 0 | 67 | 71 | 78 | 83 | 87 | 88 | 94 | 38 | 42 | 45 | 51 | 57 | 67 | 69 | 87 | 93 | 92 | 93 | 94 |
| 62/3 | 0 | 63 | 69 | 70 | 85 | 90 | 90 | 92 | 59 | 64 | 71 | 73 | 74 | 74 | 75 | 90 | 93 | 92 | 94 | 94 |
| AVER | 0 | 65 | 69 | 74 | 85 | 88 | 89 | 92 | 49 | 53 | 59 | 63 | 66 | 71 | 72 | 87 | 93 | 92 | 93 | 94 |
| Alternative 9b–73 | | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 60 | 63 | 68 | 88 | 88 | 89 | 92 | 47 | 52 | 61 | 69 | 70 | 78 | 80 | 87 | 93 | 92 | 92 | 93 |
| 73/2 | 0 | 62 | 66 | 70 | 82 | 87 | 92 | 94 | 35 | 43 | 49 | 54 | 63 | 73 | 74 | 88 | 94 | 93 | 94 | 96 |
| 73/3 | 0 | 61 | 62 | 68 | 88 | 90 | 91 | 92 | 61 | 66 | 71 | 74 | 74 | 81 | 82 | 92 | 93 | 93 | 93 | 94 |
| AVER | 0 | 61 | 64 | 69 | 86 | 88 | 91 | 93 | 48 | 54 | 60 | 66 | 69 | 77 | 79 | 89 | 93 | 93 | 93 | 94 |
| Alternative 9b–74 | | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 86 | 86 | 89 | 84 | 87 | 88 | 89 | 53 | 56 | 62 | 67 | 67 | 72 | 72 | 78 | 91 | 88 | 87 | 88 |
| 74/2 | 0 | 86 | 87 | 89 | 81 | 84 | 86 | 89 | 40 | 44 | 46 | 54 | 59 | 67 | 67 | 74 | 90 | 84 | 85 | 86 |
| 74/3 | 0 | 86 | 87 | 91 | 87 | 88 | 88 | 90 | 63 | 66 | 73 | 75 | 75 | 75 | 75 | 81 | 92 | 88 | 90 | 90 |
| AVER | 0 | 86 | 87 | 90 | 84 | 86 | 87 | 89 | 52 | 55 | 60 | 65 | 67 | 71 | 71 | 78 | 91 | 87 | 87 | 88 |

## Table D–1. Number of Days Exceeding 17.2 Deg.C Temperature – CONT

| | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 YEAR DATA | | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 86 | 87 | 91 | 88 | 90 | 92 | 94 | 63 | 66 | 73 | 75 | 75 | 81 | 82 | 92 | 94 | 93 | 94 | 96 |
| AVE | 0 | 67 | 70 | 75 | 84 | 87 | 88 | 91 | 50 | 54 | 59 | 64 | 67 | 73 | 74 | 84 | 92 | 91 | 91 | 92 |
| LOW | 0 | 60 | 62 | 68 | 81 | 83 | 85 | 88 | 35 | 41 | 44 | 51 | 57 | 67 | 67 | 74 | 90 | 84 | 85 | 86 |
| Alternative | 9c–29 | | | | | | | | | | | | | | | | | | | |
| 29/1 | 0 | 60 | 62 | 69 | 81 | 84 | 85 | 88 | 45 | 50 | 59 | 68 | 71 | 79 | 81 | 88 | 91 | 94 | 94 | 94 |
| 29/2 | 0 | 61 | 65 | 68 | 80 | 81 | 81 | 86 | 34 | 40 | 47 | 55 | 63 | 73 | 75 | 89 | 91 | 95 | 96 | 97 |
| 29/3 | 0 | 60 | 62 | 68 | 82 | 85 | 88 | 91 | 57 | 61 | 71 | 74 | 75 | 81 | 84 | 93 | 92 | 94 | 94 | 95 |
| AVER | 0 | 60 | 63 | 68 | 81 | 83 | 85 | 88 | 45 | 50 | 59 | 66 | 70 | 78 | 80 | 90 | 91 | 94 | 95 | 95 |
| Alternative | 9c–59 | | | | | | | | | | | | | | | | | | | |
| 59/1 | 0 | 63 | 67 | 72 | 75 | 84 | 84 | 86 | 51 | 54 | 62 | 64 | 67 | 69 | 71 | 82 | 91 | 88 | 89 | 89 |
| 59/2 | 0 | 66 | 71 | 76 | 75 | 80 | 83 | 87 | 38 | 42 | 45 | 54 | 61 | 67 | 69 | 74 | 93 | 89 | 89 | 90 |
| 59/3 | 0 | 62 | 68 | 70 | 80 | 84 | 87 | 90 | 60 | 64 | 71 | 73 | 75 | 76 | 76 | 86 | 93 | 92 | 92 | 92 |
| AVER | 0 | 64 | 69 | 73 | 77 | 83 | 85 | 88 | 50 | 53 | 59 | 64 | 68 | 71 | 72 | 81 | 92 | 90 | 90 | 90 |
| Alternative | 9c–62 | | | | | | | | | | | | | | | | | | | |
| 62/1 | 0 | 65 | 67 | 74 | 82 | 86 | 86 | 89 | 51 | 54 | 61 | 64 | 67 | 72 | 74 | 84 | 92 | 93 | 92 | 94 |
| 62/2 | 0 | 67 | 71 | 78 | 79 | 83 | 85 | 90 | 37 | 41 | 45 | 53 | 58 | 68 | 70 | 88 | 92 | 93 | 93 | 96 |
| 62/3 | 0 | 63 | 69 | 70 | 83 | 87 | 89 | 91 | 62 | 64 | 70 | 73 | 74 | 74 | 75 | 91 | 93 | 92 | 94 | 94 |
| AVER | 0 | 65 | 69 | 74 | 81 | 85 | 87 | 90 | 50 | 53 | 59 | 63 | 66 | 71 | 73 | 88 | 92 | 93 | 93 | 95 |
| Alternative | 9c–73 | | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 60 | 63 | 68 | 85 | 86 | 87 | 90 | 42 | 49 | 58 | 64 | 66 | 76 | 82 | 88 | 92 | 94 | 94 | 94 |
| 73/2 | 0 | 62 | 66 | 70 | 82 | 84 | 86 | 91 | 33 | 40 | 46 | 52 | 56 | 79 | 82 | 92 | 93 | 97 | 97 | 98 |
| 73/3 | 0 | 61 | 62 | 68 | 86 | 88 | 89 | 90 | 56 | 59 | 69 | 73 | 73 | 82 | 88 | 93 | 92 | 95 | 95 | 95 |
| AVER | 0 | 61 | 64 | 69 | 84 | 86 | 87 | 90 | 44 | 49 | 58 | 63 | 65 | 79 | 84 | 91 | 92 | 95 | 95 | 96 |
| Alternative | 9c–74 | | | | | | | | | | | | | | | | | | | |
| 74/1 | 0 | 86 | 86 | 89 | 86 | 88 | 89 | 89 | 53 | 59 | 64 | 66 | 66 | 71 | 72 | 77 | 91 | 88 | 88 | 88 |
| 74/2 | 0 | 86 | 87 | 89 | 84 | 86 | 87 | 89 | 41 | 45 | 47 | 55 | 58 | 66 | 66 | 74 | 91 | 83 | 84 | 84 |
| 74/3 | 0 | 86 | 87 | 91 | 89 | 88 | 88 | 90 | 63 | 69 | 74 | 75 | 75 | 75 | 75 | 79 | 94 | 90 | 91 | 92 |
| AVER | 0 | 86 | 87 | 90 | 86 | 87 | 88 | 89 | 52 | 58 | 62 | 65 | 66 | 71 | 71 | 77 | 92 | 87 | 88 | 88 |
| 5 YEAR | DATA | | | | | | | | | | | | | | | | | | | |
| HIGH | 0 | 86 | 87 | 91 | 89 | 88 | 89 | 91 | 63 | 69 | 74 | 75 | 75 | 82 | 88 | 93 | 94 | 97 | 97 | 98 |
| AVE | 0 | 67 | 70 | 75 | 82 | 85 | 86 | 89 | 48 | 53 | 59 | 64 | 67 | 74 | 76 | 85 | 92 | 92 | 92 | 93 |
| LOW | 0 | 60 | 62 | 68 | 75 | 80 | 81 | 86 | 33 | 40 | 45 | 52 | 56 | 66 | 66 | 74 | 91 | 83 | 84 | 84 |
| STA | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
| Alternative | PA–29 | | | | | | | | | | | | | | | | | | | |
| 29/1 | 37 | 65 | 68 | 69 | 70 | 75 | 81 | 93 | 44 | 49 | 58 | 65 | 67 | 73 | 77 | 84 | 92 | 92 | 91 | 93 |
| 29/2 | 35 | 68 | 68 | 72 | 66 | 77 | 85 | 93 | 34 | 40 | 46 | 51 | 52 | 69 | 72 | 86 | 93 | 92 | 92 | 94 |
| 29/3 | 39 | 65 | 67 | 70 | 71 | 78 | 83 | 92 | 57 | 60 | 69 | 73 | 73 | 78 | 81 | 91 | 93 | 93 | 93 | 94 |
| AVER | 37 | 66 | 68 | 70 | 69 | 77 | 83 | 93 | 45 | 50 | 58 | 63 | 64 | 73 | 77 | 87 | 93 | 92 | 92 | 94 |
| Alternative | PA–59 | | | | | | | | | | | | | | | | | | | |
| 59/1 | 21 | 67 | 68 | 70 | 73 | 82 | 83 | 90 | 51 | 55 | 59 | 64 | 68 | 70 | 73 | 79 | 92 | 88 | 89 | 90 |
| 59/2 | 21 | 68 | 71 | 75 | 72 | 82 | 83 | 92 | 38 | 42 | 45 | 52 | 56 | 64 | 66 | 74 | 91 | 89 | 89 | 90 |
| 59/3 | 21 | 66 | 69 | 71 | 76 | 85 | 88 | 92 | 60 | 64 | 70 | 74 | 74 | 75 | 75 | 82 | 93 | 91 | 91 | 92 |
| AVER | 21 | 67 | 69 | 72 | 74 | 83 | 85 | 91 | 50 | 54 | 58 | 63 | 66 | 70 | 71 | 78 | 92 | 89 | 90 | 91 |

## Table D−1. Number of Days Exceeding 17.2 Deg.C Temperature – CONT

| STA | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MNW | MNO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative | | PA−62 | | | | | | | | | | | | | | | | | | |
| 62/1 | 27 | 68 | 70 | 72 | 74 | 80 | 84 | 93 | 50 | 53 | 59 | 63 | 64 | 70 | 75 | 85 | 93 | 93 | 91 | 93 |
| 62/2 | 26 | 70 | 73 | 77 | 72 | 82 | 88 | 95 | 37 | 41 | 44 | 51 | 51 | 60 | 65 | 88 | 93 | 92 | 92 | 94 |
| 62/3 | 23 | 67 | 71 | 72 | 76 | 81 | 84 | 93 | 61 | 64 | 70 | 72 | 73 | 73 | 74 | 91 | 93 | 94 | 94 | 94 |
| AVER | 25 | 68 | 71 | 74 | 74 | 81 | 85 | 94 | 49 | 53 | 58 | 62 | 63 | 68 | 71 | 88 | 93 | 93 | 92 | 94 |
| Alternative | | PA−73 | | | | | | | | | | | | | | | | | | |
| 73/1 | 0 | 65 | 67 | 68 | 83 | 90 | 92 | 93 | 39 | 48 | 57 | 63 | 65 | 73 | 78 | 85 | 93 | 93 | 92 | 93 |
| 73/2 | 0 | 68 | 69 | 71 | 85 | 92 | 94 | 94 | 34 | 39 | 45 | 51 | 53 | 70 | 74 | 87 | 94 | 95 | 94 | 96 |
| 73/3 | 0 | 65 | 67 | 69 | 90 | 91 | 91 | 92 | 55 | 57 | 69 | 72 | 72 | 77 | 81 | 92 | 93 | 94 | 93 | 95 |
| AVER | 0 | 66 | 68 | 69 | 86 | 91 | 92 | 93 | 43 | 48 | 57 | 62 | 63 | 73 | 78 | 88 | 93 | 94 | 93 | 95 |
| Alternative | | PA−74 | | | | | | | | | | | | | | | | | | |
| 74/1 | 31 | 86 | 87 | 88 | 80 | 87 | 88 | 89 | 52 | 55 | 60 | 65 | 65 | 68 | 69 | 78 | 88 | 87 | 87 | 88 |
| 74/2 | 27 | 86 | 87 | 89 | 73 | 78 | 79 | 84 | 40 | 44 | 45 | 47 | 49 | 55 | 58 | 73 | 85 | 83 | 83 | 83 |
| 74/3 | 31 | 85 | 87 | 91 | 81 | 82 | 83 | 90 | 62 | 65 | 70 | 73 | 74 | 75 | 75 | 80 | 92 | 88 | 90 | 90 |
| AVER | 30 | 86 | 87 | 89 | 78 | 82 | 83 | 88 | 51 | 55 | 58 | 62 | 63 | 66 | 67 | 77 | 88 | 86 | 87 | 87 |
| 5 YEAR | | DATA | | | | | | | | | | | | | | | | | | |
| HIGH | 39 | 86 | 87 | 91 | 90 | 92 | 94 | 95 | 62 | 65 | 70 | 74 | 74 | 78 | 81 | 92 | 94 | 95 | 94 | 96 |
| AVE | 23 | 71 | 73 | 75 | 76 | 83 | 86 | 92 | 48 | 52 | 58 | 62 | 64 | 70 | 73 | 84 | 92 | 91 | 91 | 92 |
| LOW | 0 | 65 | 67 | 68 | 66 | 75 | 79 | 84 | 34 | 39 | 44 | 47 | 49 | 55 | 58 | 73 | 85 | 83 | 83 | 83 |

## DISSOLVED GAS SATURATION

### Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation

PROGRAM PERF−TDG.BAS OUTF=B:\PERF−TDG.ASC

---

RUN DATE:08−25−1993 TIME:16:26:02

This table contains the numbers of days for which the indicated three dissolved gas saturation levels are exceeded in each alternative and for each of the 6 years simulated: 1938 (medium), 1959 (medium high), 1962 (medium low), 1973 (medium low), 1974 (high), and 1977 (low). For example, under Alternative 1A−59 (Alternative 1a, year 1959), the first, second, and third rows contain number of days for 130, 120, and 120 percent saturation levels respectively. Numbers in the first column are not useful in the analysis. The “6 YEAR AVERAGE” refers to arithmetic average number of days for the 6 years at the locations indicated.

The locations are given in abbreviated form (three characters allowed):

CHJ = Chief Joseph
WEL=Wells
RRH=Rocky Reach
RIS=Rock Island
WAN=Wanapum
PRD=Priest Rapids
LWG=Lower Granite
LGS=Little Goose
LMN=Lower Monumental
IHR=Ice Harbor
MCN=McNary
JDA=John Day
TDA=The Dalles
BON=Bonneville

**Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation – CONT**

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 1a–38 (medium flow) | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 11 | 8 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 16 | 12 | 15 | 15 | 20 | 12 | 22 | 76 | 81 | 27 | 45 | 42 | 30 |
| Alternative 1a–59 (medium high flow) | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 10 | 9 | 0 | 0 | 0 | 4 |
| 3 | 110. | 23 | 16 | 12 | 23 | 18 | 28 | 10 | 19 | 76 | 77 | 25 | 40 | 34 | 26 |
| Alternative 1a–62 (medium low) | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 16 | 11 | 15 | 15 | 21 | 10 | 18 | 74 | 78 | 21 | 39 | 42 | 23 |
| Alternative 1a–73 (medium low) | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 14 | 9 | 15 | 14 | 19 | 8 | 16 | 66 | 68 | 10 | 42 | 46 | 17 |
| Alternative 1a–74 (high flow) | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 11 | 9 | 0 | 0 | 0 | 17 |
| 5 | 120. | 8 | 15 | 13 | 16 | 19 | 17 | 10 | 19 | 22 | 21 | 12 | 12 | 3 | 34 |
| 3 | 110. | 53 | 48 | 45 | 68 | 70 | 86 | 27 | 27 | 89 | 83 | 76 | 98 | 97 | 95 |
| Alternative 1a–77 (low) | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 13 | 9 | 15 | 15 | 20 | 7 | 30 | 66 | 75 | 5 | 53 | 47 | 16 |
| 6 YEAR AVERAGE FOR ALT :1a | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 3 |
| | 120. | 1 | 3 | 2 | 3 | 3 | 3 | 2 | 5 | 9 | 7 | 2 | 2 | 1 | 6 |
| | 110. | 26 | 21 | 16 | 25 | 25 | 32 | 12 | 22 | 75 | 77 | 27 | 53 | 51 | 35 |

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 1b–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 12 | 9 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 15 | 11 | 15 | 14 | 20 | 11 | 21 | 76 | 81 | 26 | 45 | 42 | 28 |
| Alternative 1b–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | 13 | 11 | 0 | 0 | 0 | 0 |
| 3 | 110. | 28 | 20 | 16 | 27 | 27 | 32 | 12 | 20 | 76 | 77 | 26 | 45 | 36 | 28 |
| Alternative 1b–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 16 | 10 | 15 | 16 | 22 | 10 | 18 | 74 | 78 | 21 | 39 | 41 | 27 |
| Alternative 1b–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 6 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 14 | 9 | 15 | 15 | 21 | 7 | 15 | 64 | 67 | 12 | 42 | 44 | 18 |

**Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation – CONT**

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 1b–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 11 | 9 | 0 | 0 | 0 | 17 |
| 5 | 120. | 6 | 14 | 12 | 16 | 19 | 16 | 10 | 19 | 22 | 21 | 11 | 11 | 5 | 32 |
| 3 | 110. | 53 | 48 | 45 | 68 | 70 | 85 | 27 | 27 | 89 | 83 | 77 | 100 | 100 | 95 |
| Alternative 1b–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 14 | 10 | 15 | 14 | 20 | 7 | 27 | 55 | 64 | 2 | 49 | 40 | 10 |
| 6 YEAR AVERAGE FOR ALT:1b | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 3 |
| | 120. | 1 | 2 | 2 | 3 | 3 | 3 | 2 | 5 | 10 | 8 | 2 | 2 | 1 | 5 |
| | 110. | 27 | 21 | 17 | 26 | 26 | 33 | 12 | 21 | 72 | 75 | 27 | 53 | 50 | 34 |

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 2c–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 7 | 6 | 0 | 0 | 0 | 13 |
| 3 | 110. | 20 | 15 | 11 | 25 | 18 | 31 | 12 | 21 | 51 | 45 | 24 | 42 | 43 | 97 |
| Alternative 2c–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 5 | 0 | 0 | 0 | 25 |
| 3 | 110. | 23 | 17 | 11 | 36 | 23 | 45 | 12 | 20 | 46 | 37 | 21 | 40 | 36 | 108 |
| Alternative 2c–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 15 | 11 | 24 | 20 | 29 | 9 | 19 | 55 | 43 | 10 | 40 | 42 | 90 |
| Alternative 2c–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 13 | 10 | 19 | 14 | 28 | 8 | 16 | 41 | 47 | 2 | 41 | 36 | 64 |
| Alternative 2c–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 11 | 10 | 0 | 0 | 0 | 27 |
| 5 | 120. | 5 | 12 | 7 | 16 | 20 | 15 | 10 | 19 | 22 | 20 | 12 | 11 | 3 | 101 |
| 3 | 110. | 57 | 58 | 52 | 88 | 91 | 97 | 27 | 27 | 74 | 61 | 70 | 95 | 101 | 127 |
| Alternative 2c–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 13 | 11 | 21 | 15 | 28 | 7 | 25 | 34 | 42 | 0 | 33 | 27 | 59 |
| 6 YEAR AVERAGE FOR: 2c | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 5 |
| | 120. | 1 | 2 | 1 | 3 | 3 | 3 | 2 | 5 | 6 | 5 | 2 | 2 | 1 | 23 |
| | 110. | 27 | 22 | 18 | 36 | 30 | 43 | 13 | 21 | 50 | 46 | 21 | 49 | 48 | 91 |

## Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation– CONT

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 2d–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 6 | 5 | 0 | 0 | 0 | 4 |
| 3 | 110. | 13 | 10 | 7 | 6 | 6 | 17 | 10 | 19 | 22 | 20 | 7 | 30 | 23 | 76 |
| Alternative 2d–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 3 | 9 | 5 | 0 | 3 | 4 | 2 | 0 | 0 | 0 | 29 |
| 3 | 110. | 37 | 34 | 28 | 36 | 44 | 54 | 8 | 16 | 18 | 18 | 32 | 56 | 49 | 97 |
| Alternative 2d–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 14 | 12 | 10 | 9 | 8 | 17 | 5 | 11 | 14 | 17 | 0 | 17 | 18 | 8 |
| Alternative 2d–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 13 | 10 | 7 | 6 | 6 | 14 | 5 | 13 | 24 | 23 | 1 | 21 | 13 | 46 |
| Alternative 2d–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 8 | 9 | 6 | 2 | 0 | 0 | 21 |
| 5 | 120. | 5 | 21 | 12 | 27 | 38 | 34 | 9 | 17 | 19 | 18 | 14 | 13 | 7 | 87 |
| 3 | 110. | 56 | 57 | 55 | 59 | 69 | 79 | 22 | 23 | 25 | 23 | 61 | 71 | 78 | 117 |
| Alternative 2d–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 13 | 10 | 7 | 6 | 5 | 16 | 5 | 20 | 25 | 26 | 1 | 22 | 17 | 51 |
| 6 YEAR AVERAGE FOR: 2d | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 3 |
| | 120. | 1 | 4 | 2 | 5 | 8 | 7 | 2 | 4 | 5 | 4 | 2 | 2 | 1 | 20 |
| | 110. | 24 | 22 | 19 | 20 | 23 | 33 | 9 | 17 | 21 | 21 | 17 | 36 | 33 | 78 |

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 4c–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 8 | 7 | 0 | 1 | 0 | 27 |
| 3 | 110. | 18 | 14 | 10 | 9 | 8 | 14 | 12 | 19 | 23 | 21 | 16 | 26 | 25 | 90 |
| Alternative 4c–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 2 | 0 | 0 | 0 | 13 |
| 3 | 110. | 23 | 15 | 13 | 17 | 29 | 42 | 8 | 15 | 19 | 19 | 12 | 38 | 32 | 109 |
| Alternative 4c–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 |
| 3 | 110. | 13 | 10 | 8 | 7 | 6 | 12 | 6 | 13 | 20 | 20 | 0 | 33 | 25 | 68 |
| Alternative 4c–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 18 | 12 | 10 | 8 | 8 | 12 | 6 | 13 | 25 | 24 | 0 | 31 | 17 | 32 |

## Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation – CONT

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 4c–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 9 | 7 | 0 | 0 | 0 | 19 |
| 5 | 120. | 3 | 9 | 5 | 16 | 29 | 25 | 8 | 16 | 18 | 18 | 10 | 11 | 5 | 88 |
| 3 | 110. | 59 | 62 | 59 | 66 | 75 | 92 | 23 | 24 | 26 | 23 | 56 | 72 | 79 | 123 |
| Alternative 4c–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 13 | 10 | 7 | 7 | 6 | 11 | 5 | 24 | 26 | 26 | 0 | 53 | 22 | 27 |
| 6 YEAR AVERAGE FOR: 4c | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 120. | 1 | 2 | 1 | 3 | 5 | 4 | 2 | 4 | 5 | 5 | 2 | 2 | 1 | 24 |
| | 110. | 24 | 21 | 18 | 19 | 22 | 31 | 10 | 18 | 23 | 22 | 14 | 42 | 33 | 75 |
| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
| Alternative 5b–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| 3 | 110. | 20 | 15 | 11 | 26 | 19 | 31 | 6 | 6 | 2 | 2 | 0 | 10 | 22 | 89 |
| Alternative 5b–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| 3 | 110. | 21 | 15 | 11 | 34 | 21 | 43 | 6 | 6 | 2 | 2 | 0 | 25 | 25 | 109 |
| Alternative 5b–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 14 | 11 | 24 | 19 | 28 | 6 | 6 | 2 | 2 | 0 | 8 | 18 | 79 |
| Alternative 5b–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 14 | 8 | 19 | 15 | 27 | 6 | 6 | 3 | 2 | 0 | 18 | 23 | 55 |
| Alternative 5b–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 |
| 5 | 120. | 3 | 10 | 5 | 16 | 20 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |
| 3 | 110. | 57 | 58 | 50 | 89 | 90 | 94 | 6 | 6 | 3 | 1 | 48 | 79 | 83 | 127 |
| Alternative 5b–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 13 | 11 | 22 | 17 | 28 | 6 | 6 | 3 | 2 | 0 | 16 | 22 | 55 |
| 6 YEAR AVERAGE FOR:5b | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| | 120. | 1 | 2 | 1 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 |
| | 110. | 26 | 22 | 17 | 36 | 30 | 42 | 6 | 6 | 3 | 2 | 8 | 26 | 32 | 86 |
| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
| Alternative 5c–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 13 | 11 | 7 | 7 | 6 | 6 | 5 | 83 | 78 | 1 | 0 | 0 | 0 | 0 |

## Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation – CONT

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 5c–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 13 | 11 | 7 | 7 | 7 | 14 | 5 | 83 | 78 | 4 | 0 | 0 | 0 | 0 |
| Alternative 5c–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 13 | 10 | 8 | 7 | 7 | 4 | 5 | 83 | 78 | 0 | 0 | 0 | 0 | 0 |
| Alternative 5c–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 13 | 10 | 7 | 6 | 3 | 2 | 5 | 83 | 77 | 0 | 0 | 1 | 0 | 0 |
| Alternative 5c–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| 5 | 120. | 0 | 4 | 2 | 7 | 19 | 15 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 22 |
| 3 | 110. | 61 | 61 | 57 | 72 | 82 | 87 | 5 | 83 | 79 | 26 | 56 | 48 | 38 | 36 |
| Alternative 5c–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 13 | 10 | 7 | 6 | 5 | 3 | 5 | 83 | 75 | 0 | 0 | 0 | 0 | 0 |
| 6 YEAR AVERAGE FOR: 5c | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | 120. | 0 | 1 | 0 | 1 | 3 | 3 | 17 | 33 | 0 | 0 | 0 | 0 | 0 | 4 |
| | 110. | 21 | 19 | 16 | 18 | 18 | 19 | 5 | 83 | 78 | 5 | 9 | 8 | 6 | 6 |

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 6b–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 8 | 6 | 0 | 0 | 0 | 10 |
| 3 | 110. | 20 | 15 | 11 | 26 | 20 | 31 | 14 | 22 | 27 | 24 | 17 | 37 | 32 | 91 |
| Alternative 6b–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 5 | 0 | 0 | 0 | 21 |
| 3 | 110. | 21 | 15 | 11 | 34 | 22 | 43 | 13 | 19 | 22 | 20 | 16 | 32 | 32 | 109 |
| Alternative 6b–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 14 | 11 | 24 | 19 | 28 | 11 | 15 | 25 | 21 | 4 | 29 | 32 | 83 |
| Alternative 6b–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 14 | 8 | 19 | 15 | 27 | 7 | 15 | 14 | 22 | 0 | 26 | 30 | 62 |
| Alternative 6b–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 3 | 0 | 0 | 0 | 30 |
| 5 | 120. | 3 | 10 | 5 | 16 | 20 | 14 | 6 | 18 | 21 | 19 | 8 | 7 | 0 | 101 |
| 3 | 110. | 57 | 58 | 50 | 89 | 90 | 94 | 34 | 29 | 50 | 50 | 68 | 93 | 97 | 127 |
| Alternative 6b–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 13 | 11 | 22 | 17 | 28 | 7 | 15 | 23 | 24 | 0 | 27 | 27 | 59 |

**Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation – CONT**

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 YEAR AVERAGE FOR:6b | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 5 |
| | 120. | 1 | 2 | 1 | 3 | 3 | 2 | 1 | 5 | 6 | 5 | 1 | 1 | 0 | 41 |
| | 110. | 26 | 22 | 17 | 36 | 31 | 42 | 14 | 19 | 27 | 27 | 18 | 41 | 42 | 88 |

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 6d–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 8 | 6 | 0 | 0 | 0 | 13 |
| 3 | 110. | 20 | 15 | 11 | 26 | 20 | 31 | 14 | 23 | 54 | 45 | 25 | 42 | 43 | 96 |
| Alternative 6d–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 5 | 0 | 0 | 0 | 21 |
| 3 | 110. | 21 | 15 | 11 | 34 | 22 | 43 | 13 | 20 | 36 | 29 | 21 | 38 | 33 | 109 |
| Alternative 6d–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 14 | 11 | 24 | 19 | 28 | 11 | 21 | 45 | 34 | 9 | 38 | 41 | 91 |
| Alternative 6d–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 14 | 8 | 19 | 15 | 27 | 7 | 15 | 38 | 43 | 0 | 36 | 34 | 61 |
| Alternative 6d–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 9 | 7 | 0 | 0 | 0 | 31 |
| 5 | 120. | 3 | 10 | 5 | 16 | 20 | 14 | 6 | 18 | 21 | 20 | 12 | 8 | 3 | 101 |
| 3 | 110. | 57 | 58 | 50 | 89 | 90 | 94 | 34 | 29 | 70 | 65 | 71 | 97 | 102 | 127 |
| Alternative 6d–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 110. | 20 | 13 | 11 | 22 | 17 | 28 | 7 | 25 | 32 | 35 | 0 | 33 | 27 | 58 |
| 6 YEAR AVERAGE FOR:6d | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 5 |
| | 120. | 1 | 2 | 1 | 3 | 3 | 2 | 1 | 5 | 6 | 5 | 2 | 1 | 1 | 23 |
| | 110. | 26 | 22 | 17 | 36 | 31 | 42 | 14 | 22 | 46 | 42 | 21 | 47 | 47 | 90 |

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 9a–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 40 | 17 | 0 | 36 | 0 | 55 |
| 3 | 110. | 19 | 16 | 12 | 11 | 11 | 22 | 67 | 54 | 93 | 85 | 29 | 124 | 130 | 132 |
| Alternative 9a–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 38 | 17 | 0 | 31 | 0 | 53 |
| 3 | 110. | 18 | 14 | 12 | 13 | 15 | 32 | 60 | 47 | 68 | 61 | 23 | 121 | 131 | 134 |
| Alternative 9a–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 34 | 15 | 0 | 54 | 0 | 60 |
| 3 | 110. | 20 | 17 | 17 | 14 | 16 | 25 | 62 | 53 | 81 | 77 | 24 | 125 | 129 | 129 |
| Alternative 9a–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 19 | 12 | 0 | 65 | 0 | 62 |
| 3 | 110. | 26 | 24 | 12 | 18 | 18 | 27 | 39 | 33 | 51 | 49 | 5 | 119 | 132 | 130 |

## Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation – CONT

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 9a–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 13 |
| 5 | 120. | 0 | 2 | 0 | 8 | 19 | 14 | 5 | 16 | 36 | 16 | 6 | 21 | 3 | 54 |
| 3 | 110. | 59 | 61 | 56 | 69 | 80 | 90 | 73 | 58 | 92 | 82 | 71 | 121 | 127 | 128 |
| Alternative 9a–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 5 | 0 | 64 | 1 | 61 |
| 3 | 110. | 34 | 32 | 28 | 30 | 26 | 30 | 21 | 24 | 37 | 36 | 4 | 119 | 131 | 132 |
| 6 YEAR AVERAGE FOR: 9a | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 4 |
| | 120. | 0 | 0 | 0 | 1 | 3 | 2 | 1 | 9 | 29 | 14 | 1 | 45 | 1 | 58 |
| | 110. | 29 | 27 | 23 | 26 | 28 | 38 | 54 | 45 | 70 | 65 | 26 | 122 | 130 | 131 |
| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
| Alternative 9b–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 8 | 43 | 6 | 0 | 0 | 0 | 56 |
| 3 | 110. | 22 | 19 | 19 | 21 | 18 | 23 | 102 | 90 | 05 | 93 | 30 | 119 | 125 | 125 |
| Alternative 9b–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 5 | 38 | 6 | 0 | 0 | 0 | 33 |
| 3 | 110. | 35 | 31 | 30 | 36 | 40 | 47 | 124 | 111 | 105 | 109 | 42 | 107 | 128 | 134 |
| Alternative 9b–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 7 | 45 | 17 | 0 | 0 | 0 | 56 |
| 3 | 110. | 20 | 16 | 16 | 15 | 15 | 26 | 113 | 103 | 108 | 103 | 23 | 123 | 124 | 125 |
| Alternative 9b–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 16 | 29 | 22 | 0 | 19 | 0 | 22 |
| 3 | 110. | 18 | 13 | 8 | 7 | 7 | 13 | 131 | 97 | 93 | 85 | 13 | 114 | 138 | 135 |
| Alternative 9b–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 10 | 7 | 0 | 0 | 0 | 14 |
| 5 | 120. | 0 | 6 | 2 | 9 | 22 | 17 | 19 | 22 | 47 | 19 | 11 | 12 | 7 | 53 |
| 3 | 110. | 68 | 76 | 71 | 86 | 92 | 97 | 94 | 86 | 98 | 91 | 73 | 109 | 122 | 119 |
| Alternative 9b–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 20 | 37 | 22 | 0 | 25 | 0 | 35 |
| 3 | 110. | 18 | 13 | 8 | 7 | 5 | 12 | 123 | 93 | 78 | 74 | 2 | 114 | 138 | 135 |
| 6 YEAR AVERAGE FOR: 9b | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 0 | 0 | 3 |
| | 120. | 0 | 1 | 0 | 2 | 4 | 3 | 15 | 13 | 40 | 15 | 2 | 9 | 1 | 43 |
| | 110. | 30 | 28 | 25 | 29 | 30 | 36 | 115 | 97 | 98 | 93 | 31 | 114 | 129 | 129 |
| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
| Alternative 9c–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 17 | 0 | 0 | 0 | 0 | 51 |
| 3 | 110. | 13 | 11 | 9 | 8 | 7 | 15 | 56 | 52 | 63 | 68 | 0 | 92 | 118 | 124 |
| Alternative 9c–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 5 | 120. | 0 | 0 | 0 | 0 | 5 | 4 | 6 | 0 | 21 | 0 | 0 | 0 | 0 | 26 |
| 3 | 110. | 27 | 24 | 22 | 25 | 26 | 31 | 50 | 47 | 64 | 65 | 18 | 69 | 106 | 123 |

## Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation – CONT

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative 9c–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 34 | 0 | 0 | 0 | 0 | 51 |
| 3 | 110. | 14 | 13 | 10 | 9 | 7 | 15 | 56 | 55 | 69 | 74 | 0 | 100 | 110 | 121 |
| Alternative 9c–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 9 | 0 | 0 | 13 | 1 | 38 |
| 3 | 110. | 13 | 10 | 7 | 7 | 6 | 12 | 51 | 54 | 45 | 49 | 7 | 111 | 134 | 135 |
| Alternative 9c–74 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 10 |
| 5 | 120. | 6 | 13 | 11 | 16 | 26 | 22 | 2 | 17 | 28 | 15 | 1 | 9 | 1 | 43 |
| 3 | 110. | 49 | 53 | 49 | 58 | 68 | 82 | 48 | 47 | 61 | 58 | 53 | 81 | 102 | 115 |
| Alternative 9c–77 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 5 | 0 | 0 | 45 | 0 | 33 |
| 3 | 110. | 13 | 11 | 7 | 6 | 6 | 14 | 43 | 55 | 46 | 46 | 0 | 115 | 132 | 135 |
| 6 YEAR AVERAGE FOR: 9c | | | | | | | | | | | | | | | |
| | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | 120. | 1 | 2 | 2 | 3 | 5 | 4 | 3 | 3 | 19 | 3 | 0 | 11 | 0 | 40 |
| | 110. | 22 | 20 | 17 | 19 | 20 | 28 | 51 | 52 | 58 | 60 | 1 | 95 | 117 | 126 |

| | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative PA–38 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 4 | 0 | 0 | 0 | 13 |
| 3 | 110. | 18 | 14 | 11 | 10 | 7 | 18 | 16 | 25 | 22 | 22 | 6 | 19 | 120 | 118 |
| Alternative PA–59 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 3 | 0 | 0 | 0 | 1 |
| 3 | 110. | 26 | 19 | 16 | 23 | 30 | 42 | 9 | 20 | 22 | 20 | 13 | 25 | 119 | 116 |
| Alternative PA–62 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 3 | 110. | 19 | 16 | 13 | 12 | 11 | 20 | 8 | 13 | 15 | 18 | 0 | 4 | 121 | 118 |
| Alternative PA–73 | | | | | | | | | | | | | | | |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 3 | 110. | 18 | 13 | 8 | 7 | 8 | 14 | 7 | 15 | 26 | 24 | 0 | 30 | 135 | 130 |

**Table D–2. Number of Days Exceeding 110, 120, and 130 Pct. TDG Saturation – CONT**

|  | TDG | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alternative PA–74 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 90 | 70 | 0 | 0 | 0 | 10 |
| 5 | 120. | 0 | 4 | 3 | 8 | 23 | 17 | 9 | 18 | 20 | 19 | 12 | 12 | 7 | 22 |
| 3 | 110. | 69 | 74 | 70 | 85 | 93 | 97 | 25 | 27 | 28 | 24 | 58 | 61 | 116 | 112 |
| Alternative PA–77 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 7 | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 120. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 20 |
| 3 | 110. | 18 | 13 | 9 | 8 | 8 | 13 | 6 | 19 | 26 | 27 | 0 | 51 | 138 | 135 |
| 6 YEAR AVERAGE FOR: PA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 130. | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 15 | 12 | 0 | 0 | 0 | 2 |
|  | 120. | 0 | 1 | 1 | 1 | 4 | 3 | 2 | 4 | 5 | 4 | 2 | 2 | 3 | 12 |
|  | 110. | 28 | 25 | 21 | 24 | 26 | 34 | 12 | 20 | 23 | 23 | 13 | 32 | 125 | 122 |

**Table D–3. Difference in No. of Days >17.2 Deg. C between the Base Case (ALT.2c) and other alternatives, averages for 1929, 59, 62, 73, 74**

NOTE: ABSOLUTE NB. DAYS ARE SHOWN FOR 2c.

| NO | ALTER | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | –2 | –1 | –1 | –4 | –1 | 0 | –6 | 0 | 1 | 1 | –1 | 0 | 0 | 1 | 4 | 1 | 1 | 1 | 3 |
| 2 | 1b | 0 | –2 | –1 | –1 | –9 | –4 | –2 | –1 | 0 | 1 | 0 | –2 | –1 | –2 | 0 | 3 | 1 | 2 | 1 | 3 |
| 3 | 2c | [0 | 65 | 67 | 69 | 78 | 82 | 85 | 87 | 35 | 41 | 53 | 61 | 64 | 69 | 70 | 78 | 89 | 87 | 88 | 88] |
| 4 | 2d | 9 | –5 | –4 | 1 | 1 | 3 | 3 | 5 | 12 | 11 | 6 | 2 | 1 | 3 | 4 | 5 | 3 | 3 | 3 | 3 |
| 5 | 4c | 0 | 0 | 0 | 2 | 5 | 5 | 3 | 4 | 13 | 11 | 6 | 3 | 2 | 3 | 4 | 5 | 3 | 4 | 4 | 4 |
| 6 | 5b | 0 | –1 | –1 | –2 | –17 | –16 | –15 | –7 | –2 | –3 | –7 | –4 | –4 | 0 | 2 | 5 | –2 | 0 | 0 | 0 |
| 7 | 5c | 0 | 1 | 0 | 2 | –4 | –7 | –8 | –9 | 7 | 5 | 2 | 2 | 1 | 5 | 7 | 11 | –5 | 4 | 4 | 6 |
| 8 | 6b | 0 | –1 | –1 | –2 | –9 | –4 | –1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 |
| 9 | 6d | 0 | –1 | –1 | –2 | –10 | –5 | –3 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 10 | 9a | 11 | 13 | 12 | 11 | 5 | 3 | 2 | 2 | 14 | 13 | 6 | 4 | 4 | 4 | 4 | 6 | 3 | 4 | 4 | 4 |
| 11 | 9b | 0 | 2 | 3 | 6 | 6 | 5 | 3 | 4 | 15 | 13 | 6 | 3 | 3 | 4 | 4 | 6 | 3 | 4 | 3 | 4 |
| 12 | 9c | 0 | 2 | 3 | 6 | 4 | 3 | 1 | 2 | 13 | 12 | 6 | 3 | 3 | 5 | 6 | 7 | 3 | 5 | 4 | 5 |
| 13 | PA | 23 | 6 | 6 | 6 | –2 | 1 | 1 | 5 | 13 | 11 | 5 | 1 | 0 | 1 | 3 | 6 | 3 | 4 | 3 | 4 |

## Table D–4. Difference in No. of Days > 17.2 Deg. C between the Base Case (ALT.2c) and other alternatives, highest numbers for 1929, 59, 62, 73, 74

NOTE: ABSOLUTE NB. DAYS ARE SHOWN FOR 2c.

| NO | ALTER | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | –1 | –1 | 0 | 4 | 2 | 2 | 0 | 3 | 5 | –6 | –1 | 0 | 2 | 9 | 4 | 1 | 0 | 9 |
| 2 | 1b | 0 | 0 | –1 | –1 | 0 | –6 | –2 | –4 | 0 | 2 | 3 | –6 | –1 | 0 | 2 | 9 | 0 | 2 | 2 | 8 |
| 3 | 2c | [0 | 77 | 80 | 85 | 83 | 88 | 90 | 92 | 62 | 63 | 66 | 79 | 79 | 80 | 80 | 88 | 93 | 93 | 94 | 92] |
| 4 | 2d | 26 | 4 | 4 | 2 | 4 | 2 | 2 | 2 | 0 | 6 | 7 | –5 | –4 | 1 | 3 | 4 | 1 | 1 | 2 | 4 |
| 5 | 4c | 0 | 3 | 3 | 2 | 7 | 3 | 3 | 2 | 1 | 6 | 9 | –4 | –4 | –2 | 0 | 4 | 3 | 4 | 4 | 6 |
| 6 | 5b | 0 | 0 | –1 | –1 | –12 | –3 | –5 | –8 | 0 | 0 –1 | 0 | 2 | 7 | 1 | 3 | 9 | 2 | 2 | 1 | 1 |
| 7 | 5c | 0 | 3 | 3 | 2 | –3 | –5 | –4 | –5 | 1 | 1 | 5 | –1 | 2 | 7 | 10 | 11 | –3 | 3 | 2 | 6 |
| 8 | 6b | 0 | 0 | –1 | –1 | 1 | –3 | 5 | 4 | –1 | –1 | 8 | 1 | 1 | 0 | 1 | 0 | 7 | 0 | 0 | 1 |
| 9 | 6d | 0 | 0 | –1 | –1 | 1 | –5 | 3 | 1 | –1 | –1 | 8 | 1 | 1 | 0 | 1 | 0 | 3 | 0 | 0 | 1 |
| 10 | 9a | 70 | 12 | 10 | 7 | 6 | 2 | –1 | 0 | –3 | 3 | 7 | –4 | –3 | –1 | 0 | 4 | 0 | 1 | 0 | 4 |
| 11 | 9b | 0 | 9 | 7 | 6 | 5 | 2 | 2 | 2 | 1 | 3 | 7 | –4 | –4 | 1 | 2 | 4 | 1 | 0 | 0 | 4 |
| 12 | 9c | 0 | 9 | 7 | 6 | 6 | 0 | –1 | –1 | 1 | 6 | 8 | –4 | –4 | 2 | 8 | 5 | 1 | 4 | 3 | 6 |
| 13 | PA | 39 | 9 | 7 | 6 | 7 | 4 | 4 | 3 | 0 | 2 | 4 | –5 | –5 | –2 | 1 | 4 | 1 | 2 | 0 | 4 |

## Table D–5. Difference in No. of Days > 17.2 Deg. C between the base case (ALT.2c) and other alternatives, lowest for 1929, 59, 62, 73, 74

NOTE: ABSOLUTE NB. DAYS ARE SHOWN FOR 2c.

| NO | ALTER | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | –4 | –4 | –2 | 3 | 5 | 5 | –27 | 0 | 0 | –4 | –1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 2 | 1b | 0 | –4 | –4 | –2 | 0 | 3 | 5 | 1 | 0 | 0 | –2 | 0 | –1 | –1 | –1 | 0 | 0 | 0 | 2 | 2 |
| 3 | 2c | [0 | 58 | 61 | 59 | 62 | 69 | 75 | 82 | 0 | 6 | 29 | 48 | 51 | 53 | 54 | 64 | 84 | 74 | 75 | 78] |
| 4 | 2d | 0 | –7 | –9 | 3 | 5 | 8 | 7 | 7 | 32 | 34 | 15 | 3 | 2 | 11 | 11 | 9 | 4 | 8 | 7 | 6 |
| 5 | 4c | 0 | 0 | –2 | 4 | 14 | 12 | 8 | 6 | 34 | 33 | 15 | 2 | 3 | 13 | 13 | 11 | 4 | 9 | 9 | 6 |
| 6 | 5b | 0 | –1 | –1 | –1 | –5 | –9 | –11 | –8 | 0 | –6 | –10 | –9 | –9 | –5 | –3 | –1 | –1 | 1 | 1 | 0 |
| 7 | 5c | 0 | 0 | –2 | 4 | 6 | 0 | –5 | –12 | 21 | 25 | 15 | 0 | –2 | 5 | 5 | 11 | –8 | 10 | 10 | 7 |
| 8 | 6b | 0 | –1 | –1 | –1 | –1 | 1 | 1 | 2 | 0 | –2 | –4 | 0 | 0 | 1 | 0 | 1 | 0 | –1 | 0 | 1 |
| 9 | 6d | 0 | –1 | –1 | –1 | –2 | 1 | 0 | 0 | 0 | –2 | –4 | 0 | 0 | 1 | 0 | 1 | 0 | –1 | 1 | 0 |
| 10 | 9a | 0 | 15 | 14 | 15 | 13 | 12 | 8 | 4 | 38 | 36 | 16 | 6 | 8 | 11 | 14 | 10 | 5 | 12 | 11 | 8 |
| 11 | 9b | 0 | 2 | 1 | 9 | 19 | 14 | 10 | 6 | 35 | 35 | 15 | 3 | 6 | 14 | 13 | 10 | 6 | 10 | 10 | 8 |
| 12 | 9c | 0 | 2 | 1 | 9 | 13 | 11 | 6 | 4 | 33 | 34 | 16 | 4 | 5 | 13 | 12 | 10 | 7 | 9 | 9 | 6 |
| 13 | PA | 0 | 7 | 6 | 9 | 4 | 6 | 4 | 2 | 34 | 33 | 15 | –1 | –2 | 2 | 4 | 9 | 1 | 9 | 8 | 5 |

**Table D–6. Difference in No. of Days > 17.2 Deg. C between the Base Case (ALT.2c) and other alternatives for 1929 (Low pool, High Temps)**

NOTE: ABSOLUTE NB. DAYS ARE SHOWN FOR 2c.

| NO | ALTER | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 2 | 2 | 1 | 12 | 8 | 6 | 1 | 0 | 1 | 0 | –6 | –2 | 3 | 8 | 12 | 3 | 3 | 3 | 6 |
| 2 | 1b | 0 | 2 | 2 | 1 | –1 | 3 | 4 | 2 | –1 | 0 | –3 | –5 | –1 | 1 | 4 | 11 | 4 | 4 | 3 | 6 |
| 3 | 2c | [0 | 60 | 62 | 63 | 67 | 75 | 79 | 84 | 31 | 34 | 53 | 67 | 68 | 70 | 71 | 78 | 87 | 89 | 90 | 89] |
| 4 | 2d | 0 | –8 | –8 | 0 | 15 | 11 | 11 | 9 | 14 | 15 | 6 | –5 | –4 | 4 | 6 | 10 | 6 | 3 | 4 | 4 |
| 5 | 4c | 0 | 0 | 2 | 2 | 17 | 10 | 8 | 7 | 15 | 14 | 4 | –4 | –4 | 1 | 3 | 8 | 5 | 4 | 4 | 5 |
| 6 | 5b | 0 | –1 | –2 | –1 | –9 | –13 | –14 | –6 | –7 | –10 | –11 | –4 | –1 | 9 | 11 | 11 | –2 | –1 | 0 | 0 |
| 7 | 5c | 0 | 0 | –1 | 2 | 4 | –2 | –5 | –8 | 0 | 1 | 2 | 5 | 7 | 11 | 14 | 15 | –5 | 3 | 3 | 6 |
| 8 | 6b | 0 | –1 | –2 | –1 | –5 | 0 | 4 | 2 | –2 | –1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 0 |
| 9 | 6d | 0 | –1 | –2 | –1 | –6 | –2 | 1 | 2 | –2 | –1 | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 0 | 0 | 0 |
| 10 | 9a | 0 | 14 | 14 | 14 | 12 | 8 | 6 | 5 | 18 | 19 | 6 | –1 | 1 | 5 | 5 | 8 | 5 | 4 | 3 | 5 |
| 11 | 9b | 0 | 0 | 1 | 5 | 17 | 12 | 10 | 8 | 18 | 19 | 6 | –3 | –1 | 3 | 4 | 9 | 6 | 3 | 3 | 5 |
| 12 | 9c | 0 | 0 | 1 | 5 | 14 | 8 | 6 | 4 | 14 | 16 | 6 | –1 | 2 | 8 | 9 | 12 | 4 | 5 | 5 | 6 |
| 13 | PA | 37 | 6 | 6 | 7 | 2 | 2 | 4 | 9 | 14 | 16 | 5 | –4 | –4 | 3 | 6 | 9 | 6 | 3 | 2 | 5 |

**Table D–7. Difference in No. of days > 17.2 Deg. C between the Base Case (ALT.2c) and other alternatives for 1962 (Ave. Pool, Ave. Temps)**

NOTE: ABSOLUTE NB. DAYS ARE SHOWN FOR 2c.

| NO | ALTER | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | 1 | 0 | –10 | –3 | –1 | –1 | 0 | 0 | 1 | 4 | 5 | 1 | 1 | 2 | 0 | 0 | 1 | 0 |
| 2 | 1b | 0 | 0 | 1 | 0 | –11 | –4 | –1 | –1 | 0 | 1 | 0 | 3 | 5 | 1 | 1 | 1 | 0 | 1 | 1 | 3 |
| 3 | 2c | [0 | 63 | 65 | 67 | 81 | 84 | 86 | 87 | 33 | 40 | 54 | 58 | 61 | 68 | 70 | 84 | 91 | 91 | 92 | 90] |
| 4 | 2d | 26 | –6 | –5 | 1 | –11 | –6 | –2 | 6 | 14 | 11 | 3 | 3 | 2 | 2 | 4 | 3 | 2 | 2 | 2 | 4 |
| 5 | 4c | 0 | 1 | 1 | 2 | 1 | 2 | 2 | 4 | 16 | 13 | 5 | 5 | 5 | 4 | 4 | 1 | 1 | 1 | 0 | 3 |
| 6 | 5b | 0 | 0 | –1 | –1 | –23 | –23 | –19 | –8 | –2 | –5 | –14 | –6 | –6 | 4 | 9 | 7 | –6 | –2 | –2 | –1 |
| 7 | 5c | 0 | 1 | 1 | 2 | –8 | –9 | –11 | –10 | 9 | 6 | –3 | 0 | 0 | 10 | 13 | 11 | –7 | 2 | 2 | 5 |
| 8 | 6b | 0 | 0 | –1 | –1 | –11 | –5 | –1 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | –2 | 0 | 0 | 1 | 0 |
| 9 | 6d | 0 | 0 | –1 | –1 | –12 | –7 | –3 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | –2 | –1 | 0 | 0 | –1 |
| 10 | 9a | 0 | 12 | 12 | 11 | 1 | 1 | 0 | 2 | 16 | 14 | 6 | 6 | 6 | 3 | 3 | 5 | 1 | 2 | 2 | 5 |
| 11 | 9b | 0 | 2 | 4 | 7 | 4 | 4 | 3 | 5 | 16 | 13 | 5 | 5 | 5 | 3 | 2 | 3 | 2 | 1 | 1 | 4 |
| 12 | 9c | 0 | 2 | 4 | 7 | 0 | 1 | 1 | 3 | 17 | 13 | 5 | 5 | 5 | 3 | 3 | 4 | 1 | 2 | 1 | 5 |
| 13 | PA | 25 | 5 | 6 | 7 | –7 | –3 | –1 | 7 | 16 | 13 | 4 | 4 | 2 | 0 | 1 | 4 | 2 | 2 | 0 | 4 |

## Table D–8. Difference in No. of days > 17.2 Deg. C between the Base Case (ALT.2c) and other alternatives for 1974 (High Pool, Low Temps)

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTER | DW | BR | OX | HC | LG | GS | LM | IH | GC | CH | WE | RR | RI | WA | PR | MW | MO | JD | TD | BO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | –1 | 0 | –3 | –2 | 0 | –29 | 1 | 5 | 2 | 0 | 0 | –1 | –1 | –1 | 0 | 0 | 0 | –1 |
| 2 | 1b | 0 | 0 | –1 | 0 | –3 | –2 | 0 | 0 | 0 | 3 | 1 | –2 | –2 | –5 | –4 | –1 | 0 | 0 | 0 | –1 |
| 3 | 2c | [0 | 76 | 79 | 82 | 82 | 83 | 84 | 86 | 45 | 50 | 56 | 61 | 62 | 66 | 67 | 74 | 87 | 82 | 83 | 86] |
| 4 | 2d | 0 | 3 | 4 | 4 | 2 | 4 | 4 | 4 | 7 | 8 | 5 | 3 | 3 | 3 | 3 | 2 | 3 | 4 | 3 | 1 |
| 5 | 4c | 0 | 2 | 2 | 4 | 4 | 4 | 4 | 4 | 8 | 8 | 7 | 6 | 6 | 5 | 5 | 4 | 3 | 5 | 4 | 1 |
| 6 | 5b | 0 | 0 | –1 | 0 | –17 | –12 | –10 | –4 | 1 | 0 | –6 | –8 | –8 | –9 | –9 | –2 | –1 | 1 | 0 | –1 |
| 7 | 5c | 0 | 3 | 2 | 4 | –6 | –5 | –5 | –8 | 6 | 4 | 0 | 0 | –1 | 1 | 1 | 4 | –3 | 5 | 5 | 2 |
| 8 | 6b | 0 | 0 | –1 | 0 | –1 | 0 | 2 | 1 | –1 | –1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 9 | 6d | 0 | 0 | –1 | 0 | –2 | –1 | –1 | 0 | –1 | –1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 10 | 9a | 0 | 12 | 11 | 9 | 4 | 4 | 3 | 3 | 5 | 5 | 4 | 4 | 6 | 4 | 5 | 4 | 3 | 6 | 5 | 2 |
| 11 | 9b | 0 | 10 | 8 | 8 | 2 | 3 | 3 | 3 | 7 | 5 | 4 | 4 | 5 | 5 | 4 | 4 | 4 | 5 | 4 | 2 |
| 12 | 9c | 0 | 10 | 8 | 8 | 4 | 4 | 4 | 3 | 7 | 8 | 6 | 4 | 4 | 5 | 4 | 3 | 5 | 5 | 5 | 2 |
| 13 | PA | 30 | 10 | 8 | 7 | –4 | –1 | –1 | 2 | 6 | 5 | 2 | 1 | 1 | 0 | 0 | 3 | 1 | 4 | 4 | 1 |

**Dissolved Gas Saturation**

## Table D–9. Difference in Number of Days Exceeding 130 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives, 6–YR Averages

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –2 |
| 2 | 1b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –2 |
| 3 | 2c | [0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 0 | 0 | 5] |
| 4 | 2d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –1 | 0 | –1 | 0 | 0 | 0 | –1 |
| 5 | 4c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –1 | 0 | 0 | 0 | –2 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –2 | –2 | –2 | 0 | 0 | 0 | 0 |
| 7 | 5c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –2 | –2 | –2 | 0 | 0 | 0 | –3 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –1 | –1 | –1 | 0 | 0 | 0 | 0 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –1 | 0 | –1 | 0 | 0 | 0 | 0 |
| 10 | 9a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –1 | –1 | –2 | 0 | 0 | 0 | –1 |
| 11 | 9b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –1 | 0 | –1 | 0 | 0 | 0 | –2 |
| 12 | 9c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | –2 | –2 | –2 | 0 | 0 | 0 | –2 |
| 13 | PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 10 | 0 | 0 | 0 | –3 |

### Table D–10. Difference in Number of Days Exceeding 130 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives, Highest of 6–Yrs.

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −1 | 0 | 0 | 0 | −10 |
| 2 | 1b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −1 | 0 | 0 | 0 | −10 |
| 3 | 2c | [0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 11 | 10 | 0 | 0 | 0 | 27] |
| 4 | 2d | 0 | 0 | 0 | 0 | 2 | 0 | 0 | −1 | −2 | −4 | 2 | 0 | 0 | −6 |
| 5 | 4c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −2 | −3 | 0 | 0 | 0 | −8 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −9 | −11 | −10 | 0 | 0 | 0 | 1 |
| 7 | 5c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −9 | −11 | −10 | 0 | 0 | 0 | −17 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −4 | −5 | −7 | 0 | 0 | 0 | 3 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −2 | −2 | −3 | 0 | 0 | 0 | 4 |
| 10 | 9a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −6 | −8 | −8 | 0 | 0 | 0 | −14 |
| 11 | 9b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −1 | −1 | −3 | 0 | 0 | 0 | −13 |
| 12 | 9c | 0 | 0 | 0 | 0 | 2 | 0 | 0 | −9 | −10 | −10 | 0 | 0 | 0 | −17 |
| 13 | PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 79 | 60 | 0 | 0 | 0 | −17 |

### Table D–11. Difference in Number of Days Exceeding 130 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives, Lowest for 6–yrs.

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2c | [0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0] |
| 4 | 2d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 4c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 5c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 9a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 11 | 9b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 9c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

**Table D–12. Difference in Number of Days Exceeding 130 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives for 1974 (High TDG)**

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −1 | 0 | 0 | 0 | −10 |
| 2 | 1b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −1 | 0 | 0 | 0 | −10 |
| 3 | 2c | [0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 11 | 10 | 0 | 0 | 0 | 27] |
| 4 | 2d | 0 | 0 | 0 | 0 | 2 | 0 | 0 | −1 | −2 | −4 | 2 | 0 | 0 | −6 |
| 5 | 4c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −2 | −3 | 0 | 0 | 0 | −8 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −9 | −11 | −10 | 0 | 0 | 0 | 1 |
| 7 | 5c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −9 | −11 | −10 | 0 | 0 | 0 | −17 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −4 | −5 | −7 | 0 | 0 | 0 | 3 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −2 | −2 | −3 | 0 | 0 | 0 | 4 |
| 10 | 9a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −6 | −6 | −8 | 0 | 0 | 0 | −14 |
| 11 | 9b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −1 | −1 | −3 | 0 | 0 | 0 | −13 |
| 12 | 9c | 0 | 0 | 0 | 0 | 2 | 0 | 0 | −9 | −10 | −10 | 0 | 0 | 0 | −17 |
| 13 | PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −0 | −79 | 60 | 0 | 0 | 0 | −17 |

**Table D–13. Difference in Number of Days Exceeding 130 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives for 1959 (Average Water)**

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2c | [0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0] |
| 4 | 2d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 4c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 5c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 9a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 11 | 9b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 12 | 9c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 13 | PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### Table D–14. Difference in Number of Days Exceeding 130 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives for 1973 (Low Flow)

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2c | [0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0] |
| 4 | 2d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 4c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 5c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 9a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 11 | 9b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 9c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### Table D–15. Difference in Number of Days Exceeding 120 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives, Average of 6–yrs

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | −17 |
| 2 | 1b | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 0 | 0 | 0 | −18 |
| 3 | 2c | [ 1 | 2 | 1 | 3 | 3 | 3 | 2 | 5 | 6 | 5 | 2 | 2 | 1 | 23] |
| 4 | 2d | 0 | 2 | 1 | 2 | 5 | 4 | 0 | −1 | −1 | −1 | 0 | 0 | 0 | −3 |
| 5 | 4c | 0 | 0 | 0 | 0 | 2 | 1 | 0 | −1 | −1 | 0 | 0 | 0 | 0 | 1 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | −1 | −2 | −5 | −6 | −5 | −2 | −2 | −1 | −2 |
| 7 | 5c | −1 | −1 | −1 | −2 | 0 | 0 | 15 | 28 | −6 | −5 | −2 | −2 | −1 | −19 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | −1 | −1 | 0 | 0 | 0 | −1 | −1 | −1 | −1 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | −1 | −1 | 0 | 0 | 0 | 0 | −1 | 0 | 0 |
| 10 | 9a | −1 | −2 | −1 | −2 | 0 | −1 | −1 | 4 | 23 | 9 | −1 | 43 | 0 | 35 |
| 11 | 9b | −1 | −1 | −1 | −1 | 1 | 0 | 13 | 8 | 34 | 10 | 0 | 7 | 0 | 20 |
| 12 | 9c | 0 | 0 | 1 | 0 | 2 | 1 | 1 | −2 | 13 | −2 | −2 | 9 | −1 | 17 |
| 13 | PA | −1 | −1 | 0 | −2 | 1 | 0 | 0 | −1 | −1 | −1 | 0 | 0 | 2 | −11 |

**Table D–16. Difference in Number of Days Exceeding 120 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives, Highest of 6–yrs.**

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 3 | 3 | 6 | 0 | −1 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | −67 |
| 2 | 1b | 1 | 2 | 5 | 0 | −1 | 1 | 0 | 0 | 0 | 1 | −1 | 0 | 2 | −69 |
| 3 | 2c | [5 | 12 | 7 | 16 | 20 | 15 | 10 | 19 | 22 | 20 | 12 | 11 | 3 | 101] |
| 4 | 2d | 0 | 9 | 5 | 11 | 18 | 19 | −1 | −2 | −3 | −2 | 2 | 2 | 4 | −14 |
| 5 | 4c | −2 | −3 | −2 | 0 | 9 | 10 | −2 | −3 | −4 | −2 | −2 | 0 | 2 | −13 |
| 6 | 5b | −2 | −2 | −2 | 0 | 0 | −1 | −10 | −19 | −22 | −20 | −12 | −11 | −3 | −1 |
| 7 | 5c | −5 | −8 | −5 | −9 | −1 | 0 | 40 | 31 | −22 | −20 | −12 | −11 | −3 | −79 |
| 8 | 6b | −2 | −2 | −2 | 0 | 0 | −1 | −4 | −1 | −1 | −1 | −4 | −4 | −3 | 0 |
| 9 | 6d | −2 | −2 | −2 | 0 | 0 | −1 | −4 | −1 | −1 | 0 | 0 | −3 | 0 | 0 |
| 10 | 9a | −5 | −10 | −7 | −8 | −1 | −1 | −5 | −3 | 18 | −3 | −6 | 54 | 0 | −39 |
| 11 | 9b | −5 | −6 | −5 | −7 | 2 | 2 | 18 | 3 | 25 | 2 | −1 | 14 | 4 | −45 |
| 12 | 9c | 1 | 1 | 4 | 0 | 6 | 7 | −4 | −2 | 12 | −5 | −11 | 34 | −2 | −50 |
| 13 | PA | −5 | −8 | −4 | −8 | 3 | 2 | −1 | −1 | −2 | −1 | 0 | 1 | 9 | −79 |

**Table D–17. Difference in Number of Days Exceeding 120 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives, Lowest of 6–yrs.**

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 1b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 2c | [0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0] |
| 4 | 2d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 4c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 5c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 9a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 5 | 0 | 21 | 0 | 53 |
| 11 | 9b | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 5 | 29 | 6 | 0 | 0 | 0 | 22 |
| 12 | 9c | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 5 | 0 | 0 | 0 | 0 | 26 |
| 13 | PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

### Table D–18. Difference in Number of Days Exceeding 120 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives for 1974 (High TDG)

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 3 | 3 | 6 | 0 | −1 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | −67 |
| 2 | 1b | 1 | 2 | 5 | 0 | −1 | 1 | 0 | 0 | 0 | 1 | −1 | 0 | 2 | −69 |
| 3 | 2c | [ 5 | 12 | 7 | 16 | 20 | 15 | 10 | 19 | 22 | 20 | 12 | 11 | 3 | 101] |
| 4 | 2d | 0 | 9 | 5 | 11 | 18 | 19 | −1 | −2 | −3 | −2 | 2 | 2 | 4 | −14 |
| 5 | 4c | −2 | −3 | −2 | 0 | 9 | 10 | −2 | −3 | −4 | −2 | −2 | 0 | 2 | −13 |
| 6 | 5b | −2 | −2 | −2 | 0 | 0 | −1 | −10 | −19 | −22 | −20 | −12 | −11 | −3 | −1 |
| 7 | 5c | −5 | −8 | −5 | −9 | −1 | 0 | 40 | −19 | −22 | −20 | −12 | −11 | −3 | −79 |
| 8 | 6b | −2 | −2 | −2 | 0 | 0 | −1 | −4 | −1 | −1 | −1 | −4 | −4 | −3 | 0 |
| 9 | 6d | −2 | −2 | −2 | 0 | 0 | −1 | −4 | −1 | −1 | 0 | 0 | −3 | 0 | 0 |
| 10 | 9a | −5 | −10 | −7 | −8 | −1 | −1 | −5 | −3 | 14 | −4 | −6 | 10 | 0 | −47 |
| 11 | 9b | −5 | −6 | −5 | −7 | 2 | 2 | 9 | 3 | 25 | −1 | −1 | 1 | 4 | −48 |
| 12 | 9c | 1 | 1 | 4 | 0 | 6 | 7 | −8 | −2 | 6 | −5 | −11 | −2 | −2 | −58 |
| 13 | PA | −5 | −8 | −4 | −8 | 3 | 2 | −1 | −1 | −2 | −1 | 0 | 1 | 4 | −79 |

### Table D–19. Difference in Number of Days Exceeding 120 Pct Saturation Between the Base Case (Alt. 2) and Other Alternatives for 1959 (Ave. TDG)

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | 4 | 0 | 0 | 0 | −21 |
| 2 | 1b | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 7 | 6 | 0 | 0 | 0 | −25 |
| 3 | 2c | [0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 6 | 5 | 0 | 0 | 0 | 25] |
| 4 | 2d | 0 | 0 | 0 | 3 | 9 | 5 | 0 | −2 | −2 | −3 | 0 | 0 | 0 | 4 |
| 5 | 4c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −2 | −2 | −3 | 0 | 0 | 0 | −12 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −5 | −6 | −5 | 0 | 0 | 0 | −9 |
| 7 | 5c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 45 | −6 | −5 | 0 | 0 | 0 | −25 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −4 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −4 |
| 10 | 9a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 32 | 12 | 0 | 31 | 0 | 28 |
| 11 | 9b | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 32 | 1 | 0 | 0 | 0 | 8 |
| 12 | 9c | 0 | 0 | 0 | 0 | 5 | 4 | 6 | −5 | 15 | −5 | 0 | 0 | 0 | 1 |
| 13 | PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | −2 | −1 | −2 | 0 | 0 | 0 | −24 |

### Table D–20. Difference in Number of Days Exceeding 120 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives for 1973 (Low TDG)

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 0 | 0 | 0 | 0 |
| 2 | 1b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 6 | 0 | 0 | 0 | 0 |
| 3 | 2c | [0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0] |
| 4 | 2d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 4c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6 | 5b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 7 | 5c | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 6b | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 9 | 6d | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 10 | 9a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 19 | 12 | 0 | 65 | 0 | 62 |
| 11 | 9b | 0 | 0 | 0 | 0 | 0 | 0 | 28 | 16 | 29 | 22 | 0 | 19 | 0 | 22 |
| 12 | 9c | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 9 | 0 | 0 | 13 | 1 | 38 |
| 13 | PA | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |

### Table D–21. Difference in Number of Days Exceeding 110 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives, Averages of 6–yrs

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | −1 | −1 | −2 | −11 | −5 | −11 | −1 | 1 | 25 | 31 | 6 | 4 | 3 | −56 |
| 2 | 1b | 0 | −1 | −1 | −10 | −4 | −10 | −1 | 0 | 22 | 29 | 6 | 4 | 3 | −57 |
| 3 | 2c | [27 | 22 | 18 | 36 | 30 | 43 | 13 | 21 | 50 | 46 | 21 | 49 | 48 | 91] |
| 4 | 2d | −3 | 0 | 1 | −16 | −7 | −10 | −4 | −4 | −29 | −25 | −4 | −13 | −15 | −13 |
| 5 | 4c | −3 | −1 | 0 | −17 | −8 | −12 | −3 | −3 | −27 | −24 | −7 | −7 | −15 | −16 |
| 6 | 5b | −1 | 0 | −1 | 0 | 0 | −1 | −7 | −15 | −47 | −44 | −13 | −23 | −16 | −5 |
| 7 | 5c | −6 | −3 | −2 | −18 | −12 | −24 | −8 | 62 | 28 | −41 | −12 | −41 | −42 | −85 |
| 8 | 6b | −1 | 0 | −1 | 0 | 1 | −1 | 1 | −2 | −23 | −19 | −3 | −8 | −6 | −2 |
| 9 | 6d | −1 | 0 | −1 | 0 | 1 | −1 | 1 | 1 | −4 | −4 | 0 | −2 | −1 | −1 |
| 10 | 9a | 2 | 5 | 5 | −10 | −2 | −5 | 41 | 24 | 20 | 19 | 5 | 73 | 82 | 40 |
| 11 | 9b | 3 | 6 | 7 | −7 | 0 | −7 | 102 | 76 | 48 | 47 | 10 | 65 | 81 | 38 |
| 12 | 9c | −5 | −2 | −1 | −17 | −10 | −15 | 38 | 31 | 8 | 14 | −8 | 46 | 69 | 35 |
| 13 | PA | 1 | 3 | 3 | −12 | −4 | −9 | −1 | −1 | −27 | −23 | −8 | −17 | 77 | 31 |

## Table D–22. Difference in Number of Days Exceeding 110 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives, Highest of 6–yrs

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | −4 | −10 | −7 | −20 | −21 | −11 | 0 | 3 | 15 | 22 | 6 | 3 | −4 | −32 |
| 2 | 1b | −4 | −10 | −7 | −20 | −21 | −12 | 0 | 0 | 15 | 22 | 7 | 5 | −1 | −32 |
| 3 | 2c | [57 | 58 | 52 | 88 | 91 | 97 | 27 | 27 | 74 | 61 | 70 | 95 | 101 | 127] |
| 4 | 2d | −1 | −1 | 3 | −29 − | 22 | −18 | −5 | −4 | −49 | −35 | −9 | −24 | −23 | −10 |
| 5 | 4c | 2 | 4 | 7 | −22 | −16 | −5 | −4 | −3 | −48 | −35 | −14 | −23 | −22 | −4 |
| 6 | 5b | 0 | 0 | −2 | 1 | −1 | −3 | −21 | −21 | −71 | −59 | −22 | −16 | −18 | 0 |
| 7 | 5c | 4 | 3 | 5 | −16 | −9 | −10 | −22 | 56 | 5 | −35 | −14 | −47 | −63 | −91 |
| 8 | 6b | 0 | 0 | −2 | 1 | −1 | −3 | 7 | 2 | −24 | −11 | −2 | −2 | −4 | 0 |
| 9 | 6d | 0 | 0 | −2 | 1 | −1 | −3 | 7 | 2 | −4 | 4 | 1 | 2 | 1 | 0 |
| 10 | 9a | 2 | 3 | 4 | −19 | −11 | −7 | 46 | 31 | 19 | 24 | 1 | 30 | 31 | 7 |
| 11 | 9b | 11 | 18 | 19 | −2 | 1 | 0 | 104 | 84 | 34 | 48 | 3 | 28 | 37 | 8 |
| 12 | 9c | −8 | −5 | −3 | −30 | −23 | −15 | 29 | 28 | −5 | 13 | −17 | 20 | 33 | 8 |
| 13 | PA | 12 | 16 | 18 | −3 | 2 | 0 | −2 | 0 | −46 | −34 | −12 | −34 | 37 | 8 |

## Table D–23. Difference in Number of Days Exceeding 110 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives, Lowest of 6–yrs.

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 0 | −1 | −4 | 0 | −9 | 0 | 0 | 32 | 31 | 5 | 6 | 7 | −43 |
| 2 | 1b | 0 | 1 | −1 | −4 | 0 | −8 | 0 | −1 | 21 | 27 | 2 | 6 | 9 | −49 |
| 3 | 2c | [20 | 13 | 10 | 19 | 14 | 28 | 7 | 16 | 34 | 37 | 0 | 33 | 27 | 59] |
| 4 | 2d | −7 | −3 | −3 | −13 | −9 | −14 | −2 | −5 | −20 | −20 | 0 | −16 | −14 | −13 |
| 5 | 4c | −7 | −3 | −3 | −12 | −8 | −17 | −2 | −3 | −15 | −18 | 0 | −7 | −10 | −32 |
| 6 | 5b | 0 | 0 | −2 | 0 | 1 | −1 | −1 | −10 | −32 | −36 | 0 | −25 | −9 | −4 |
| 7 | 5c | −7 | −3 | −3 | −13 | −11 | −26 | −2 | 67 | 41 | −37 | 0 | −33 | −27 | −59 |
| 8 | 6b | 0 | 0 | −2 | 0 | 1 | −1 | 0 | −1 | −20 | −17 | 0 | −7 | 0 | 0 |
| 9 | 6d | 0 | 0 | −2 | 0 | 1 | −1 | 0 | −1 | −2 | −8 | 0 | 0 | 0 | −1 |
| 10 | 9a | −2 | 1 | 2 | −8 | −3 | −6 | 14 | 8 | 3 | −1 | 4 | 86 | 100 | 69 |
| 11 | 9b | −2 | 0 | −2 | −12 | −9 | −16 | 87 | 70 | 44 | 37 | 2 | 74 | 95 | 60 |
| 12 | 9c | −7 | −3 | −3 | −13 | −8 | −16 | 36 | 31 | 11 | 9 | 0 | 36 | 75 | 56 |
| 13 | PA | −2 | 0 | −2 | −12 | −7 | −15 | −1 | −3 | −19 | −19 | 0 | −29 | 89 | 53 |

### Table D–24. Difference in Number of Days Exceeding 110 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives for 1974 (High TDG)

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | −4 | −10 | −7 | −20 | −21 | −11 | 0 | 0 | 15 | 22 | 6 | 3 | −4 | −32 |
| 2 | 1b | −4 | −10 | −7 | −20 | −21 | −12 | 0 | 0 | 15 | 22 | 7 | 5 | −1 | −32 |
| 3 | 2c | [57 | 58 | 52 | 88 | 91 | 97 | 27 | 27 | 74 | 61 | 70 | 95 | 101 | 127] |
| 4 | 2d | −1 | −1 | 3 | −29 | −22 | −18 | −5 | −4 | −49 | −38 | −9 | −24 | −23 | −10 |
| 5 | 4c | 2 | 4 | 7 | −22 | −16 | −5 | −4 | −3 | −48 | −38 | −14 | −23 | −22 | −4 |
| 6 | 5b | 0 | 0 | −2 | 1 | −1 | −3 | −21 | −21 | −71 | −60 | −22 | −16 | −18 | 0 |
| 7 | 5c | 4 | 3 | 5 | −16 | −9 | −10 | −22 | 56 | 5 | −35 | −14 | −47 | −63 | −91 |
| 8 | 6b | 0 | 0 | −2 | 1 | −1 | −3 | 7 | 2 | −24 | −11 | −2 | −2 | −4 | 0 |
| 9 | 6d | 0 | 0 | −2 | 1 | −1 | −3 | 7 | 2 | −4 | 4 | 1 | 2 | 1 | 0 |
| 10 | 9a | 2 | 3 | 4 | −19 | −11 | −7 | 46 | 31 | 18 | 21 | 1 | 26 | 26 | 1 |
| 11 | 9b | 11 | 18 | 19 | −2 | 1 | 0 | 67 | 59 | 24 | 30 | 3 | 14 | 21 | −8 |
| 12 | 9c | −8 | −5 | −3 | −30 | −23 | −15 | 21 | 20 | −13 | −3 | −17 | −14 | 1 | −12 |
| 13 | PA | 12 | 16 | 18 | −3 | 2 | 0 | −2 | 0 | −46 | −37 | −12 | −34 | 15 | −15 |

### Table D–25. Difference in TDG Number of Days Exceeding 110 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives for 1959 (Av. TDG)

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | −1 | 1 | −13 | −5 | −17 | −2 | −1 | 30 | 40 | 4 | 0 | −2 | −82 |
| 2 | 1b | 5 | 3 | 5 | −9 | 4 | −13 | 0 | 0 | 30 | 40 | 5 | 5 | 0 | −80 |
| 3 | 2c | [23 | 17 | 11 | 36 | 23 | 45 | 12 | 20 | 46 | 37 | 21 | 40 | 36 | 108] |
| 4 | 2d | 14 | 17 | 17 | 0 | 21 | 9 | −4 | −4 | −28 | −19 | 11 | 16 | 13 | −11 |
| 5 | 4c | 0 | −2 | 2 | −19 | 6 | −3 | −4 | −5 | −27 | −18 | −9 | −2 | −4 | 1 |
| 6 | 5b | −2 | −2 | 0 | −2 | −2 | −2 | −6 | −14 | −44 | −35 | −21 | −15 | −11 | 1 |
| 7 | 5c | −10 | −6 | −4 | −29 | −16 | −31 | −7 | 63 | 32 | −33 | −21 | −40 | −36 | −108 |
| 8 | 6b | −2 | −2 | 0 | −2 | −1 | −2 | 1 | −1 | −24 | −17 | −5 | −8 | −4 | 1 |
| 9 | 6d | −2 | −2 | 0 | −2 | −1 | −2 | 1 | 0 | −10 | −8 | 0 | −2 | −3 | 1 |
| 10 | 9a | −5 | −3 | 1 | −23 | −8 | −13 | 48 | 27 | 22 | 24 | 2 | 81 | 95 | 26 |
| 11 | 9b | 12 | 14 | 19 | 0 | 17 | 2 | 112 | 91 | 59 | 72 | 21 | 67 | 92 | 26 |
| 12 | 9c | 4 | 7 | 11 | −11 | 3 | −14 | 38 | 27 | 18 | 28 | −3 | 29 | 70 | 15 |
| 13 | PA | 3 | 2 | 5 | −13 | 7 | −3 | −3 | 0 | −24 | −17 | −8 | −15 | 83 | 8 |

### Table D–26. Difference in Number of Days Exceeding 110 Pct Saturation Between the Base Case (Alt. 2c) and Other Alternatives for 1973 (Low Flow)

NOTE: ABSOLUTE NUMBER OF DAYS ARE SHOWN FOR ALT.2C

| NO | ALTERN | CHJ | WEL | RRH | RIS | WAN | PRD | LWG | LGS | LMN | IHR | MCN | JDA | TDA | BON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1a | 0 | 1 | −1 | −4 | 0 | −9 | 0 | 0 | 25 | 21 | 8 | 1 | 10 | −47 |
| 2 | 1b | 0 | 1 | −1 | −4 | 1 | −7 | −1 | −1 | 23 | 20 | 10 | 1 | 8 | −46 |
| 3 | 2c | [20 | 13 | 10 | 19 | 14 | 28 | 8 | 16 | 41 | 47 | 2 | 41 | 36 | 64] |
| 4 | 2d | −7 | −3 | −3 | −13 | −8 | −14 | −3 | −3 | −17 | −24 | −1 | −20 | −23 | −18 |
| 5 | 4c | −2 | −1 | 0 | −11 | −6 | −16 | −2 | −3 | −16 | −23 | −2 | −10 | −19 | −32 |
| 6 | 5b | 0 | 1 | −2 | 0 | 1 | −1 | −2 | −10 | −38 | −45 | −2 | −23 | −13 | −9 |
| 7 | 5c | −7 | −3 | −3 | −13 | −11 | −26 | −3 | 67 | 36 | −47 | −2 | −40 | −36 | −64 |
| 8 | 6b | 0 | 1 | −2 | 0 | 1 | −1 | −1 | −1 | −27 | −25 | −2 | −15 | −6 | −2 |
| 9 | 6d | 0 | 1 | −2 | 0 | 1 | −1 | −1 | −1 | −3 | −4 | −2 | −5 | −2 | −3 |
| 10 | 9a | 6 | 11 | 2 | −1 | 4 | −1 | 31 | 17 | 10 | 2 | 3 | 78 | 96 | 66 |
| 11 | 9b | −2 | 0 | −2 | −12 | −7 | −15 | 123 | 81 | 52 | 38 | 11 | 73 | 102 | 71 |
| 12 | 9c | −7 | −3 | −3 | −12 | −8 | −16 | 43 | 38 | 4 | 2 | 5 | 70 | 98 | 71 |
| 13 | PA | −2 | 0 | −2 | −12 | −6 | −14 | −1 | −1 | −15 | −23 | −2 | −11 | 99 | 66 |

Graphs are also provided in the following pages showing: 1) the daily variations of the water quality parameter involved; and 2) the number of days exceeding given threshold values (performance indices).

Graphic displays in the latter group are of two types. The first shows the number of days thresholds are exceeded for each alternative at all locations modeled; it provides a graphical comparison of the performances of all alternatives at all sites. The second shows the high, average, and low numbers of days exceeded for all alternatives at one selected location. This graphic provides the range of values to be expected at that one site under various regulation scenarios.

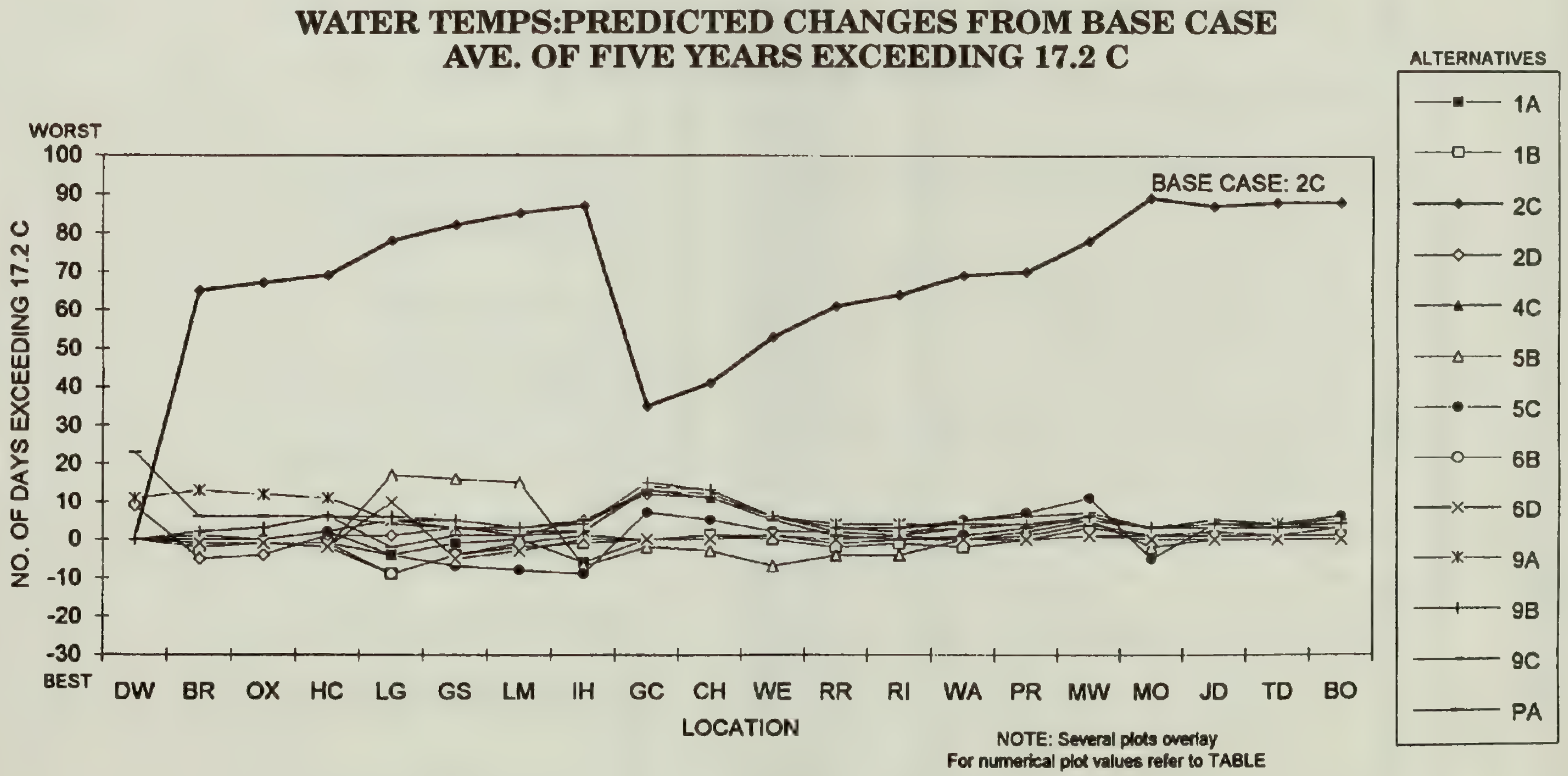


Figure D–1. Water Temps:Predicted Changes from Base Case Year=Ave

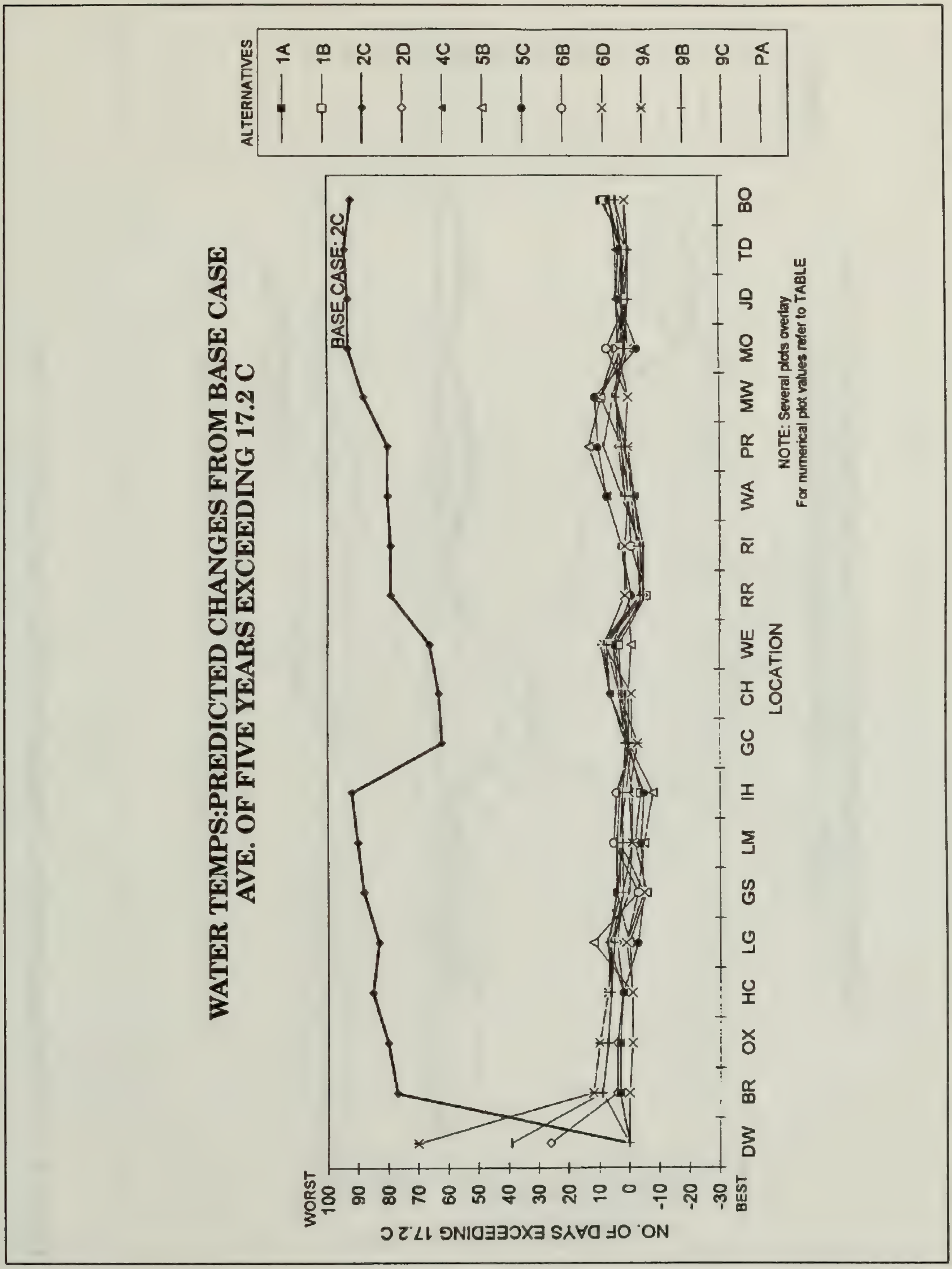


Figure D–2. Bon Water Temps:Predicted Changes from Base Case, Highest of 5 Years

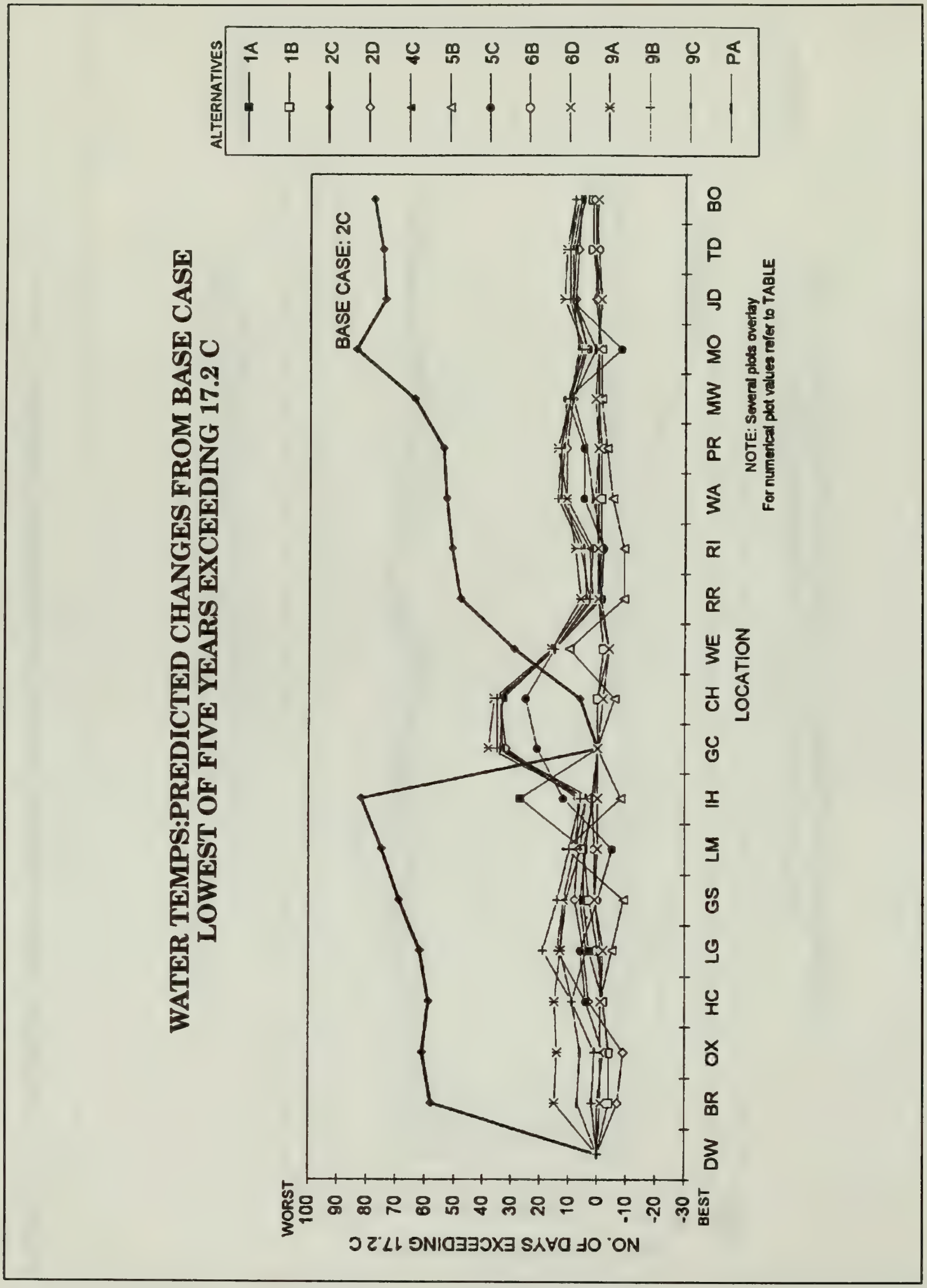


Figure D–3. Water Temps:Predicted Changes from Base Case, Lowest of 5 Years

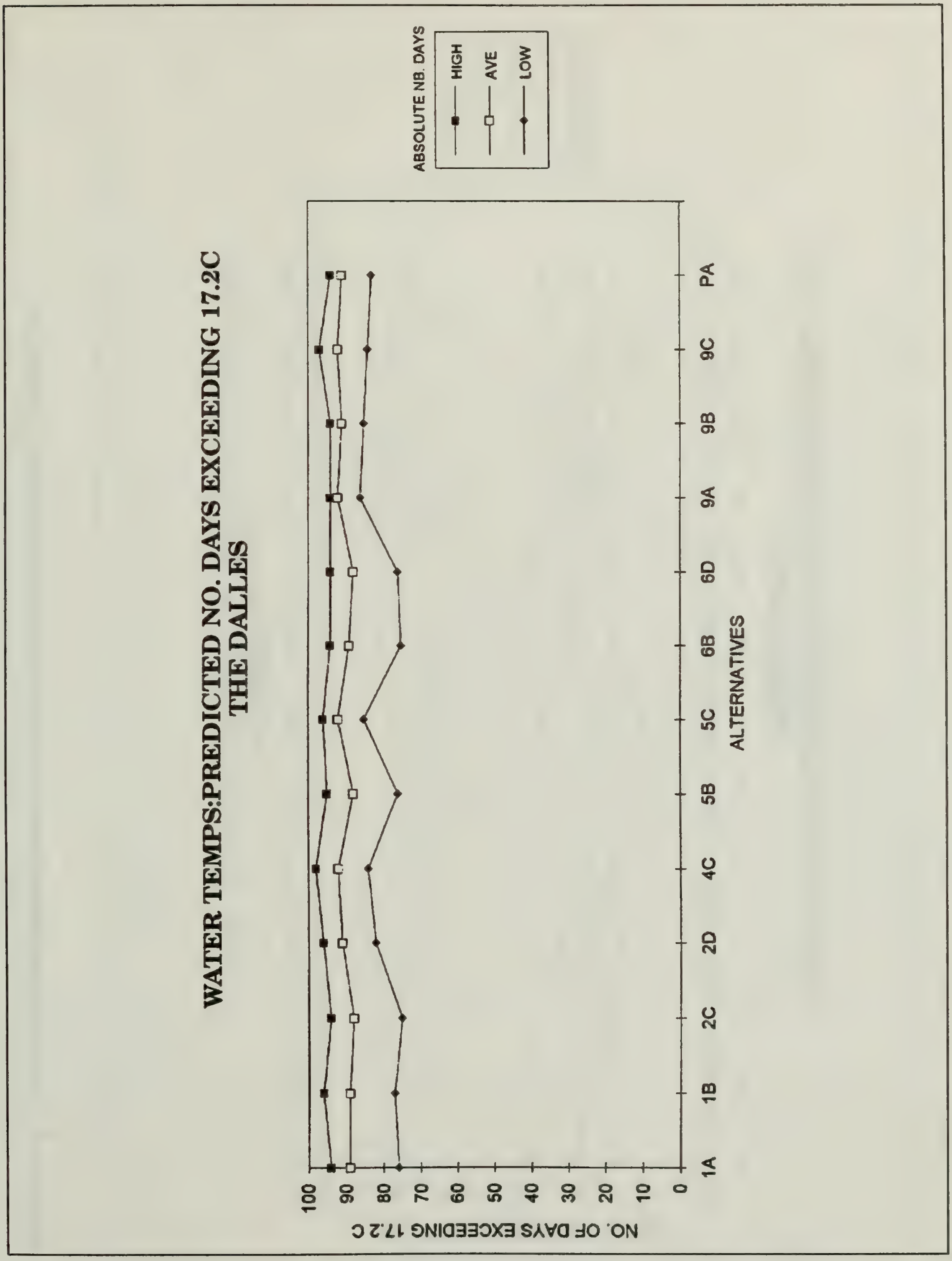


Figure D–4. The Dalles Water Temps:Predicted No. Days Exceeding 17.2 Deg. C

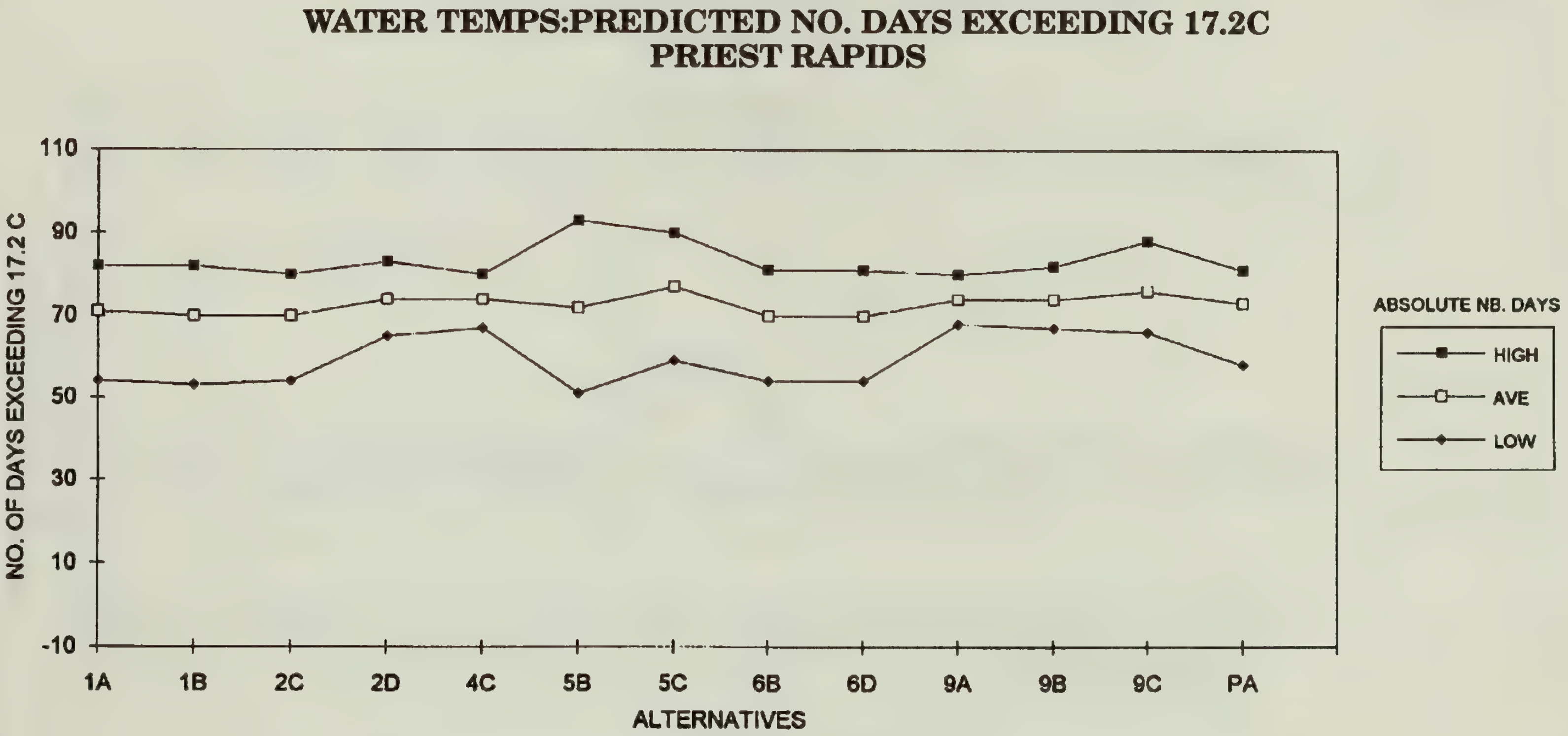


Figure D–5. Priest Rapids Water Temps:Predicted No. Days Exceeding 17.2 Deg. C

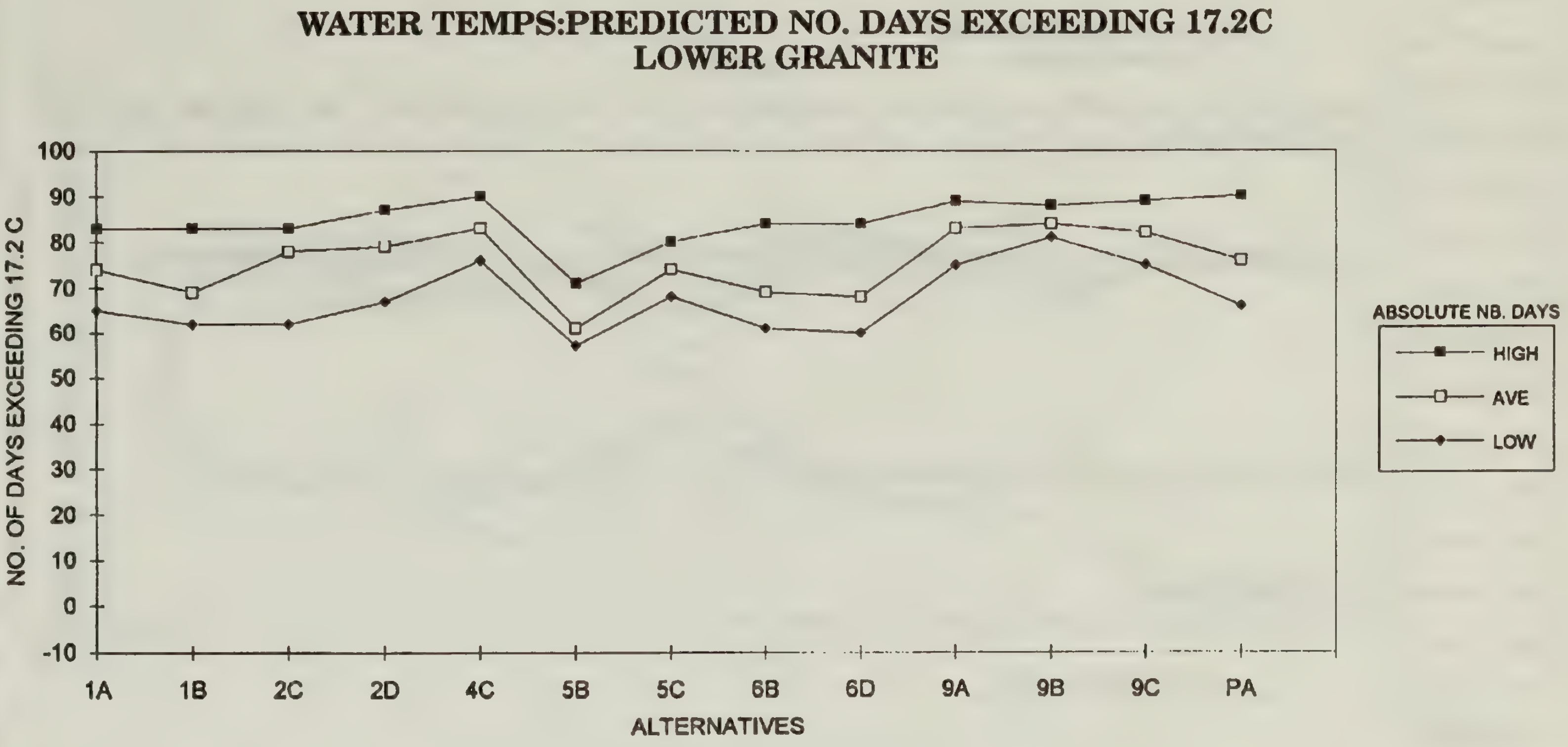


Figure D–6. Lower Granite Water Temps:Predicted No. Days Exceeding 17.2 Deg. C

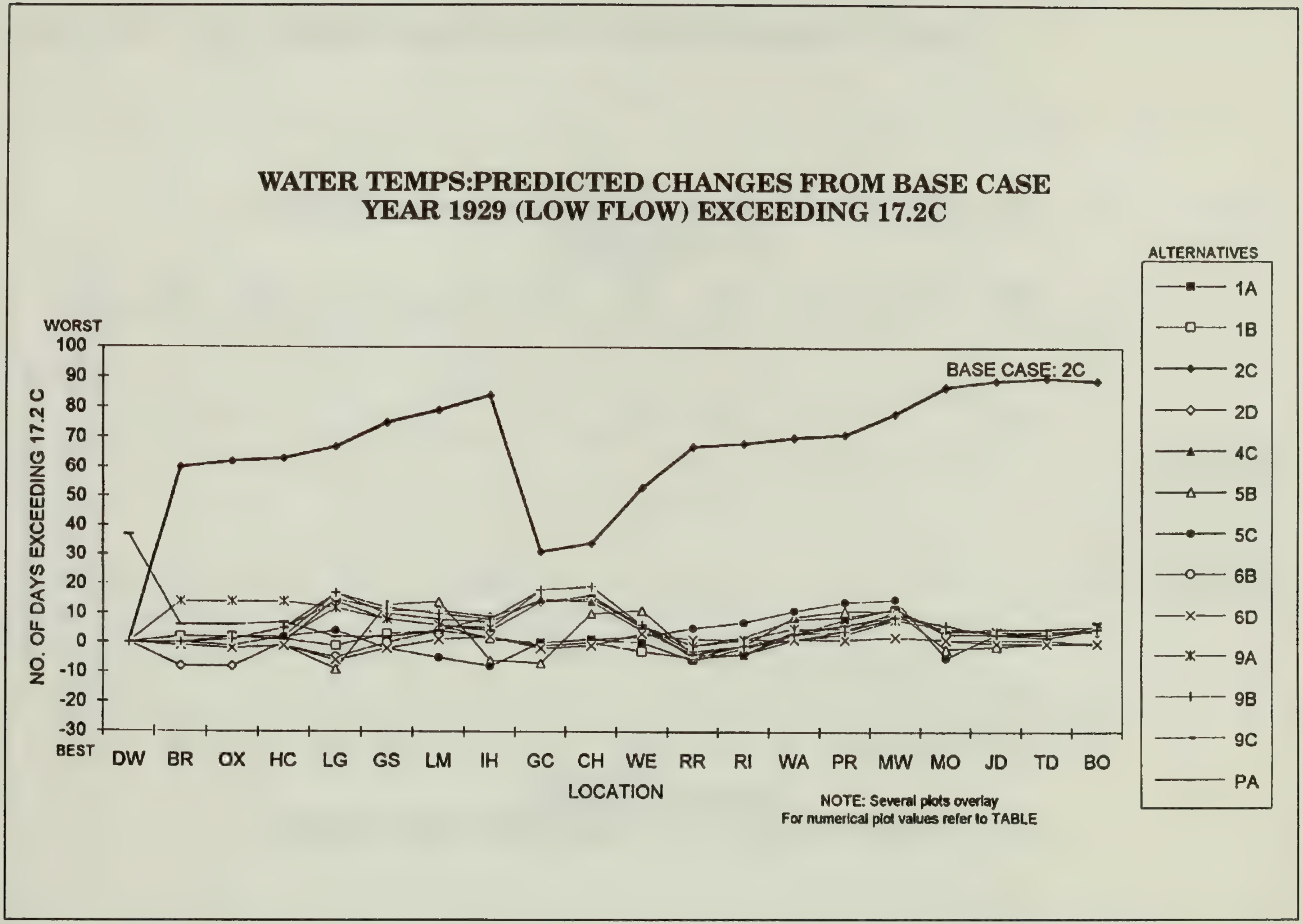


Figure D–7. Water Temps:Predicted Changes from Base Case, Year=1929 (Low Flow)

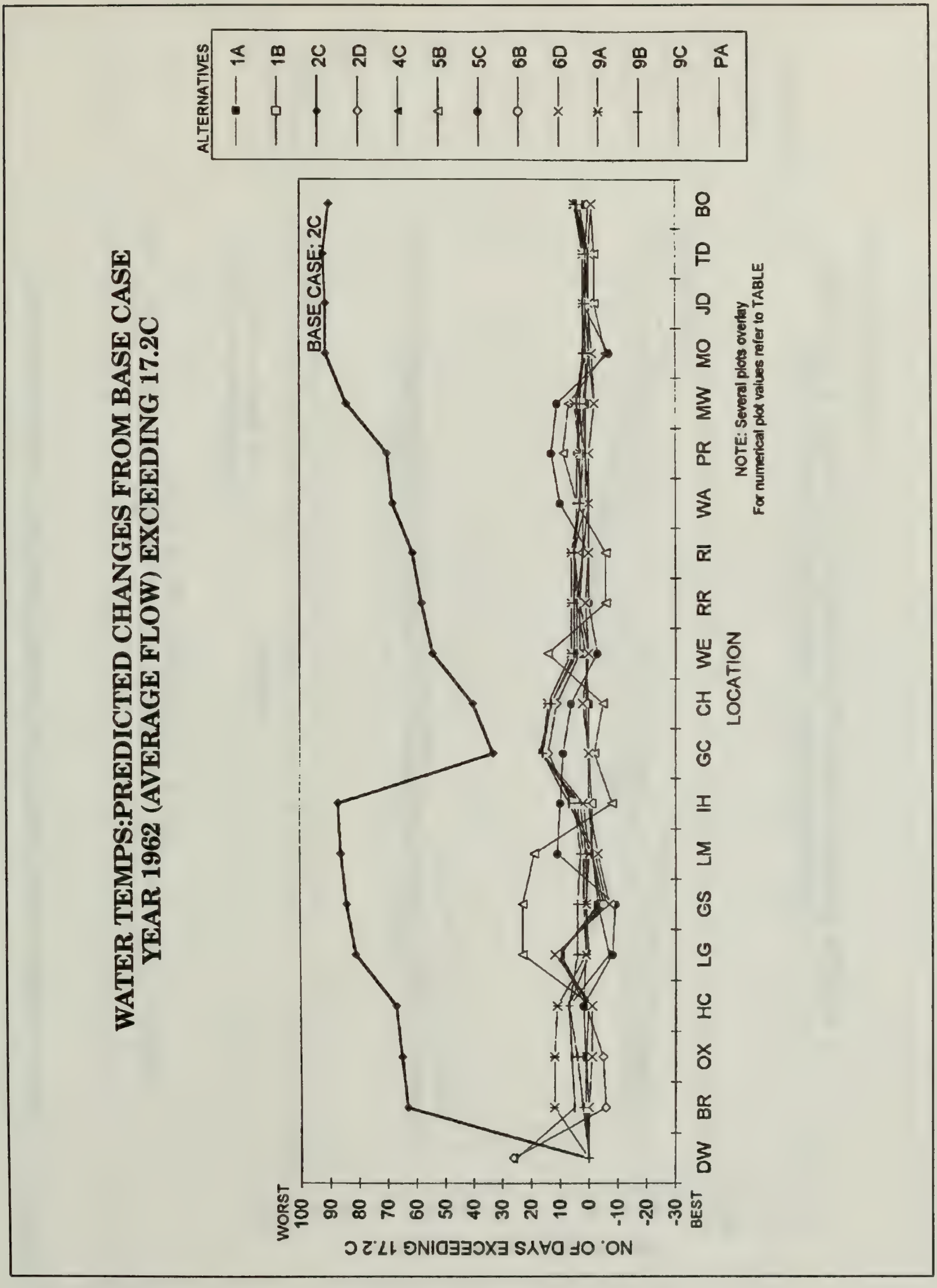


Figure D–8. Water Temps:Predicted Changes from Base Case, Year=1962 (Average Flow)

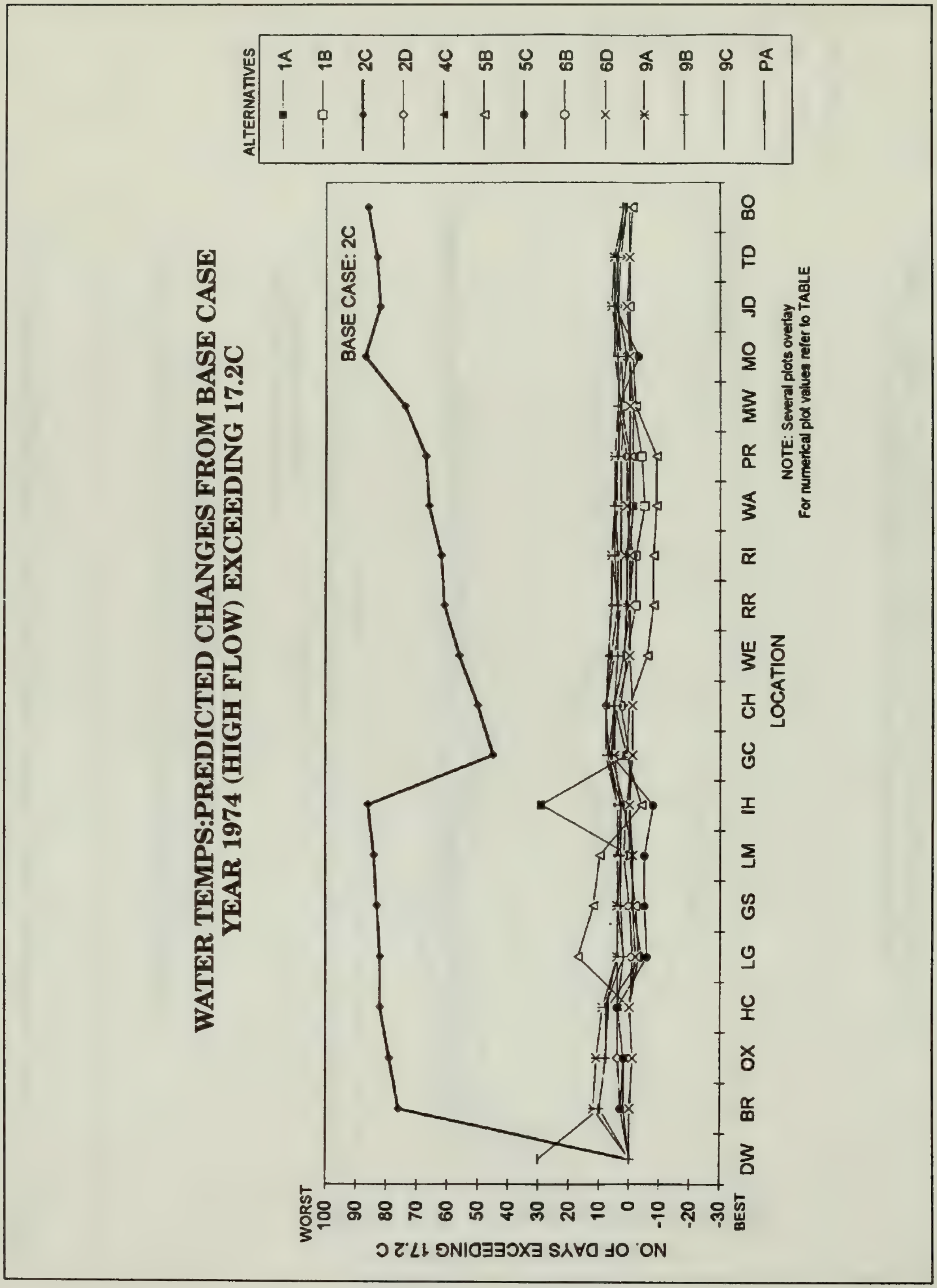
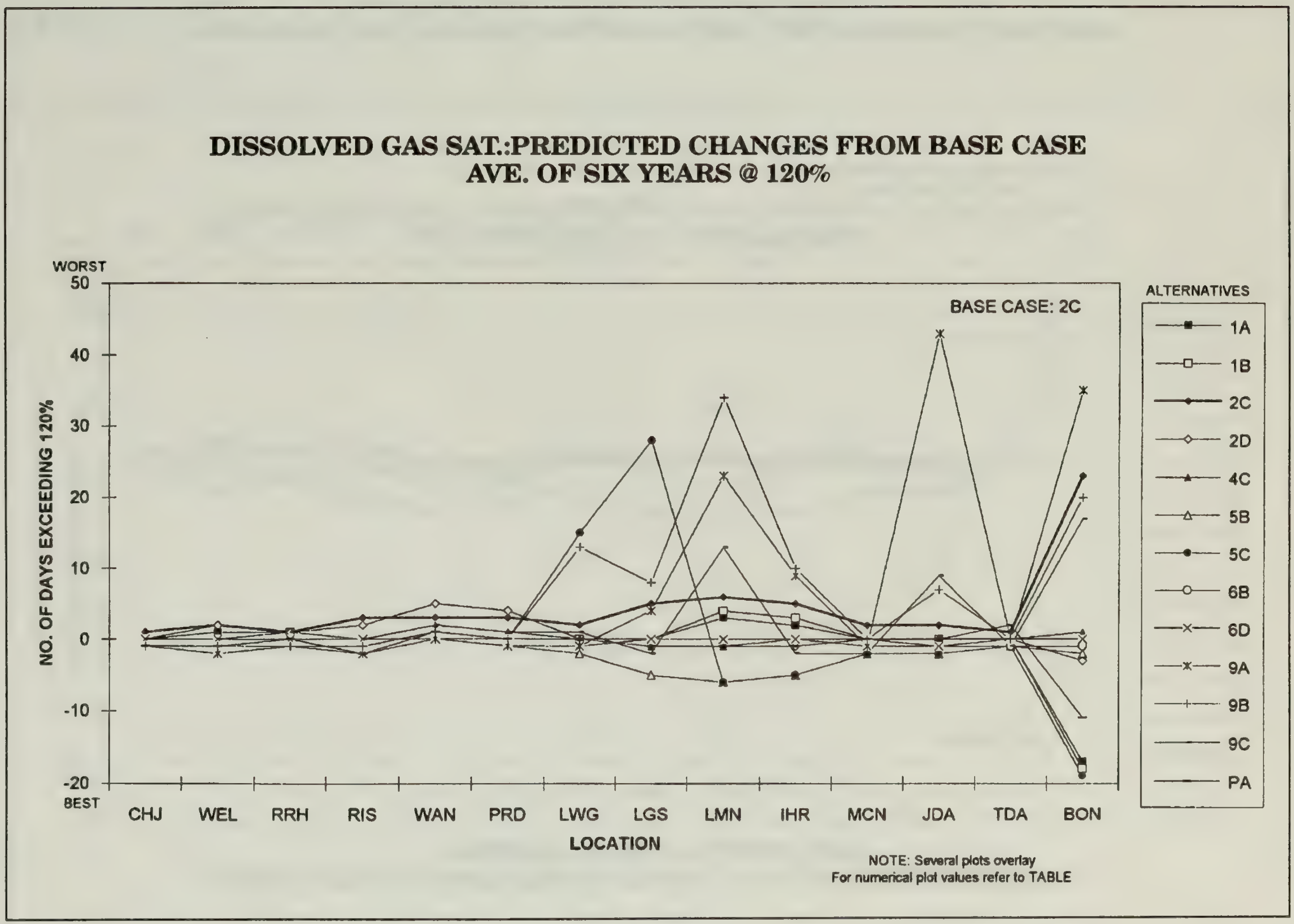


**Figure D–9.** Water Temps:Predicted Changes from Base Case, Year=1974 (High Flow)



NOTE: Several plots overlay
For numerical plot values refer to TABLE

Figure D–10. Dissolved Gas Sat.:Predicted Changes from Base Case, 6–Year Ave, Base=120%

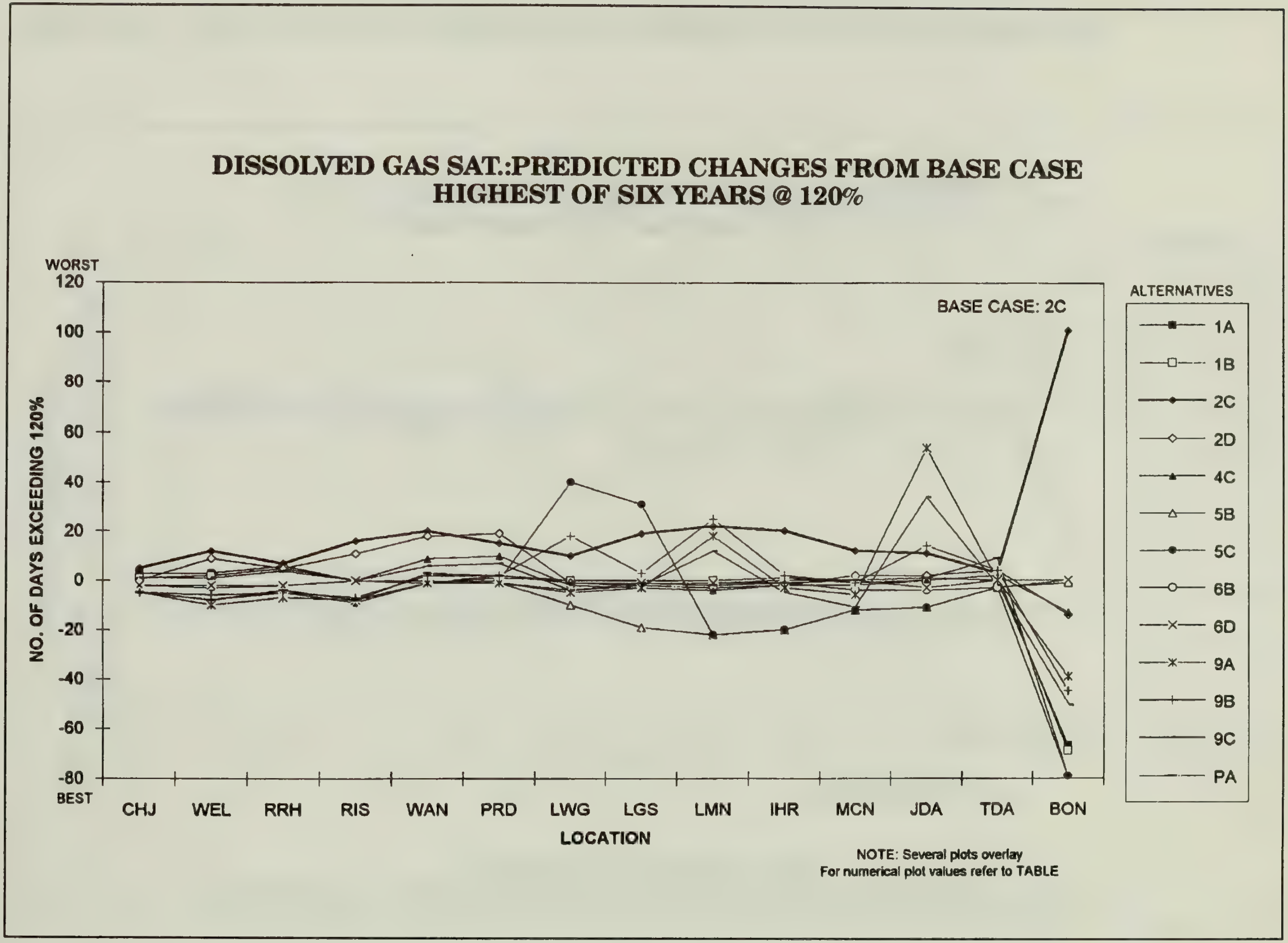


Figure D–11. Dissolved Gas Sat.:Predicted Changes from Base Case, 6–Year High, Base=120%

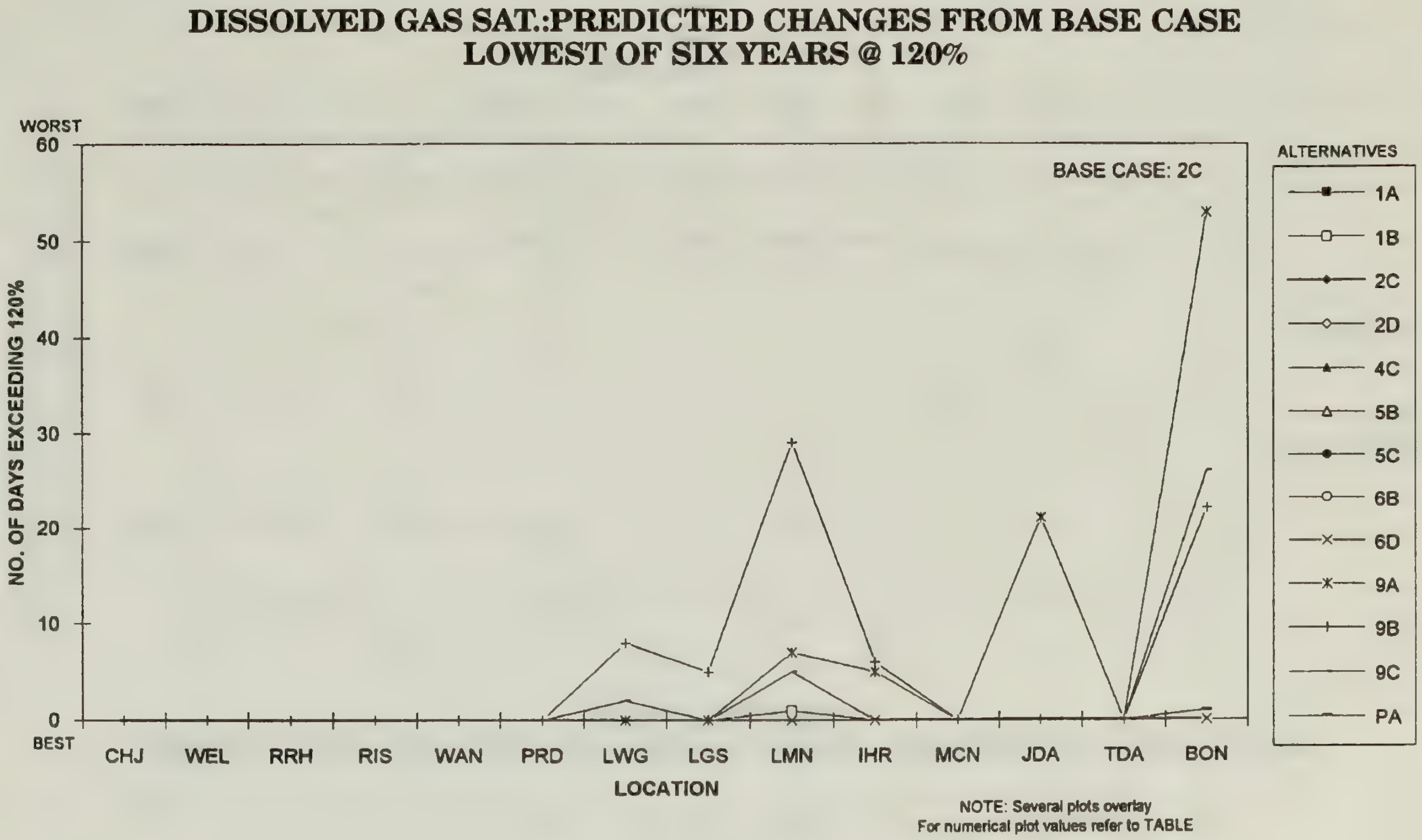


Figure D–12. Dissolved Gas Sat.:Predicted Changes from Base Case, 6–Year Low, Base=120%

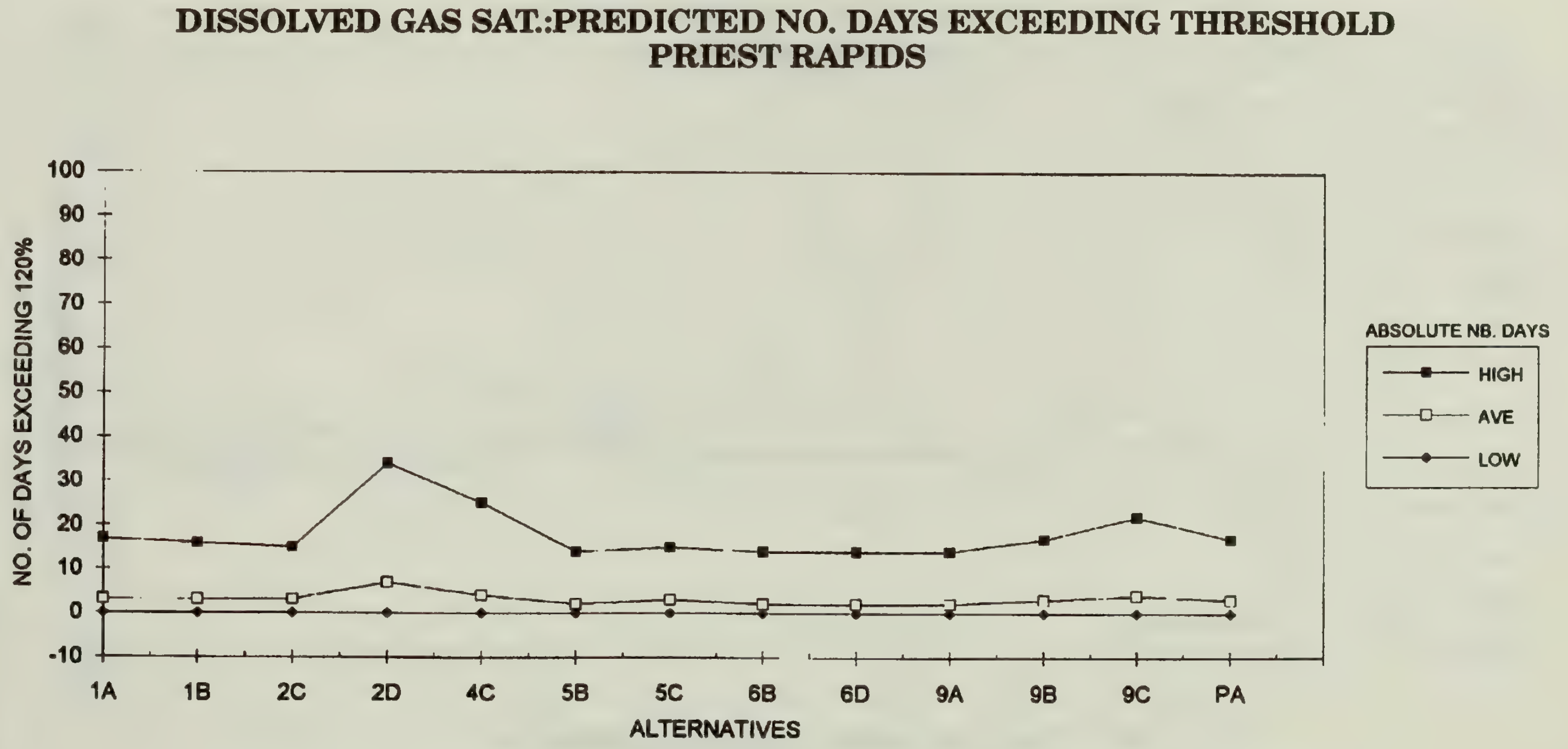


Figure D–13. Priest Rapids Dissolved Gas Sat.:Predicted No. Days Exceeding 120% Threshold

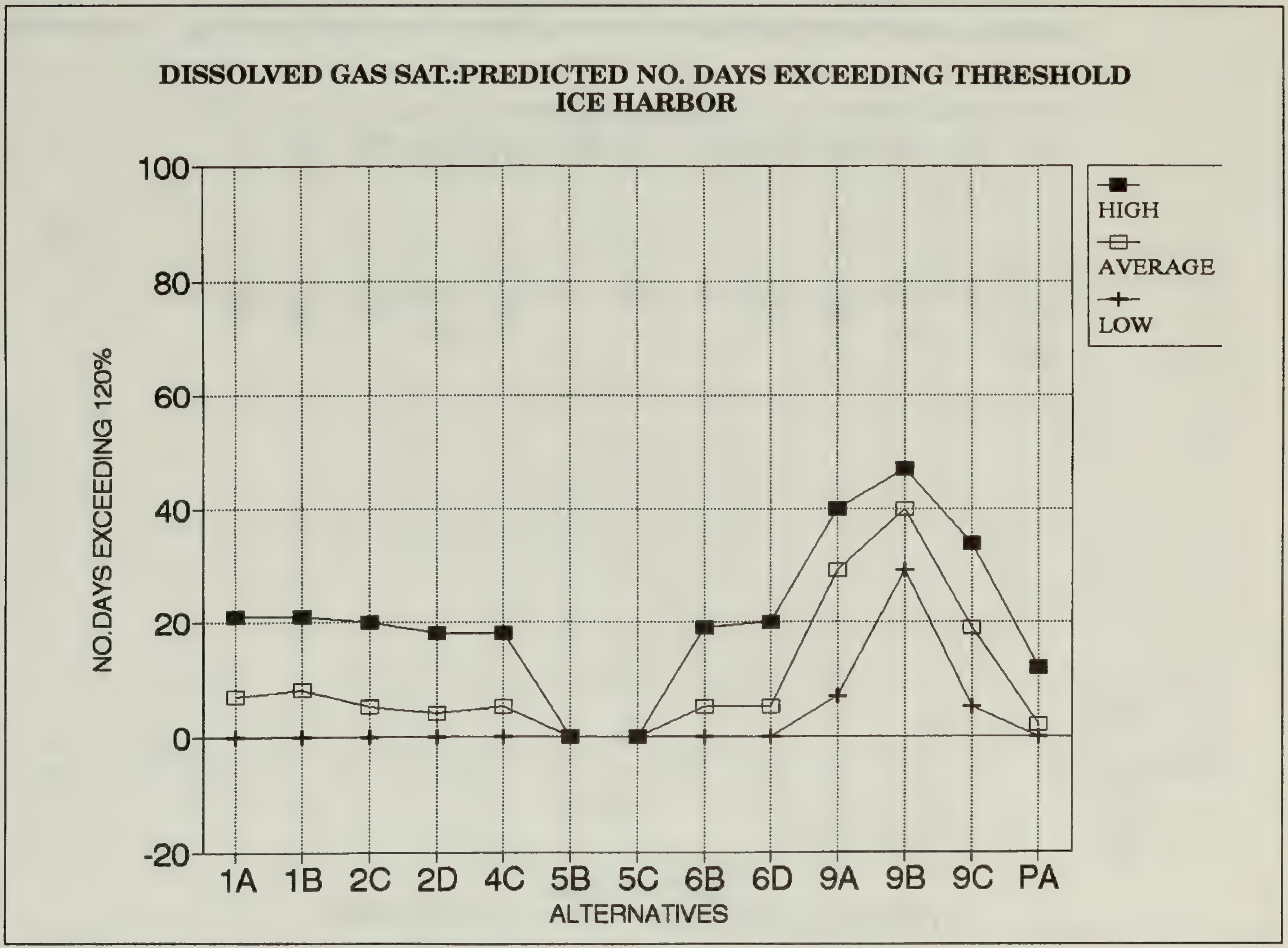


Figure D–14. Ice Harbor Dissolved Gas Sat.:Predicted No. Days Exceeding 120% Threshold

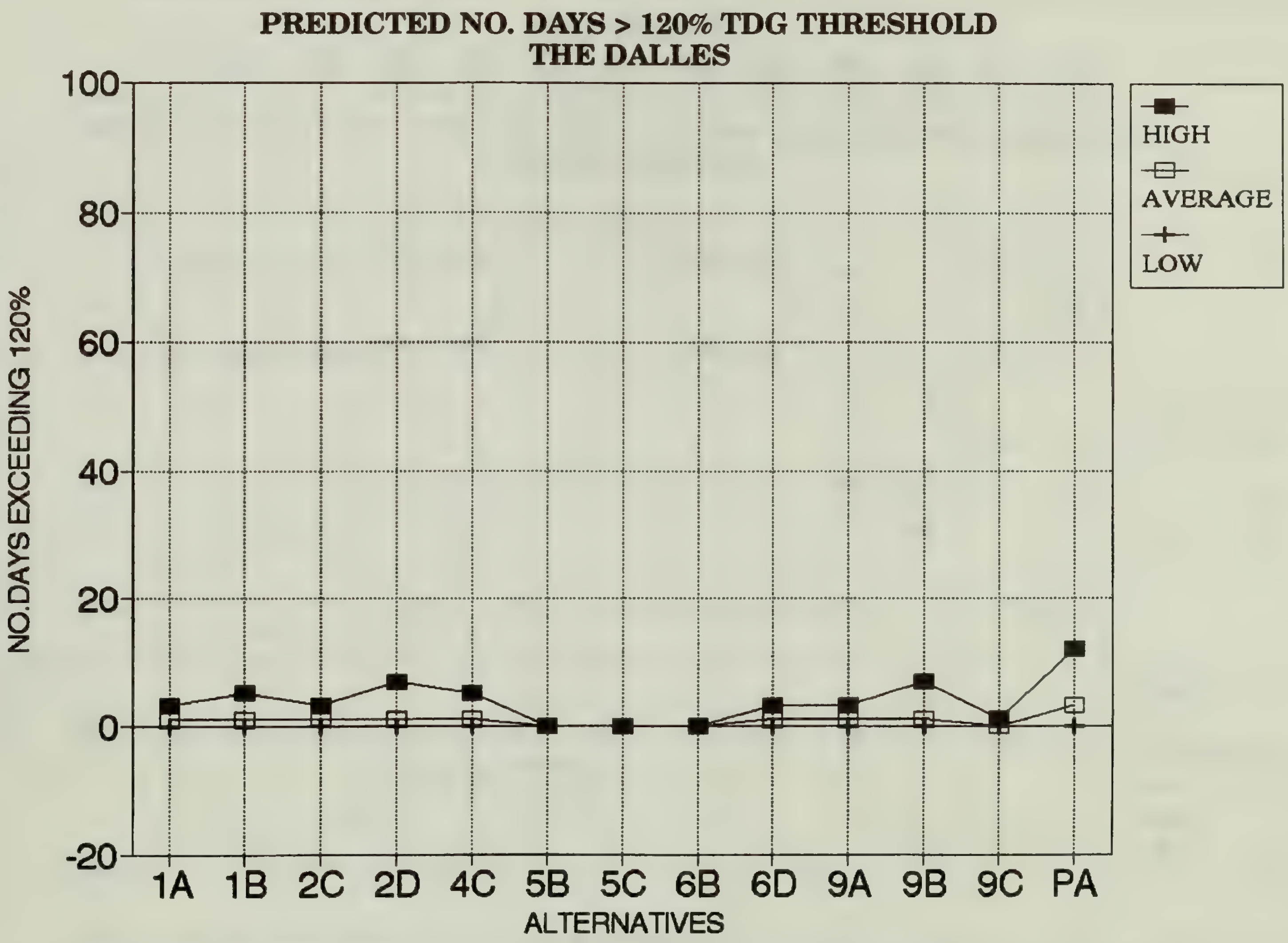


**Figure D–15.** **The Dalles Dissolved Gas Sat.:Predicted No. Days Exceeding 120% Threshold**

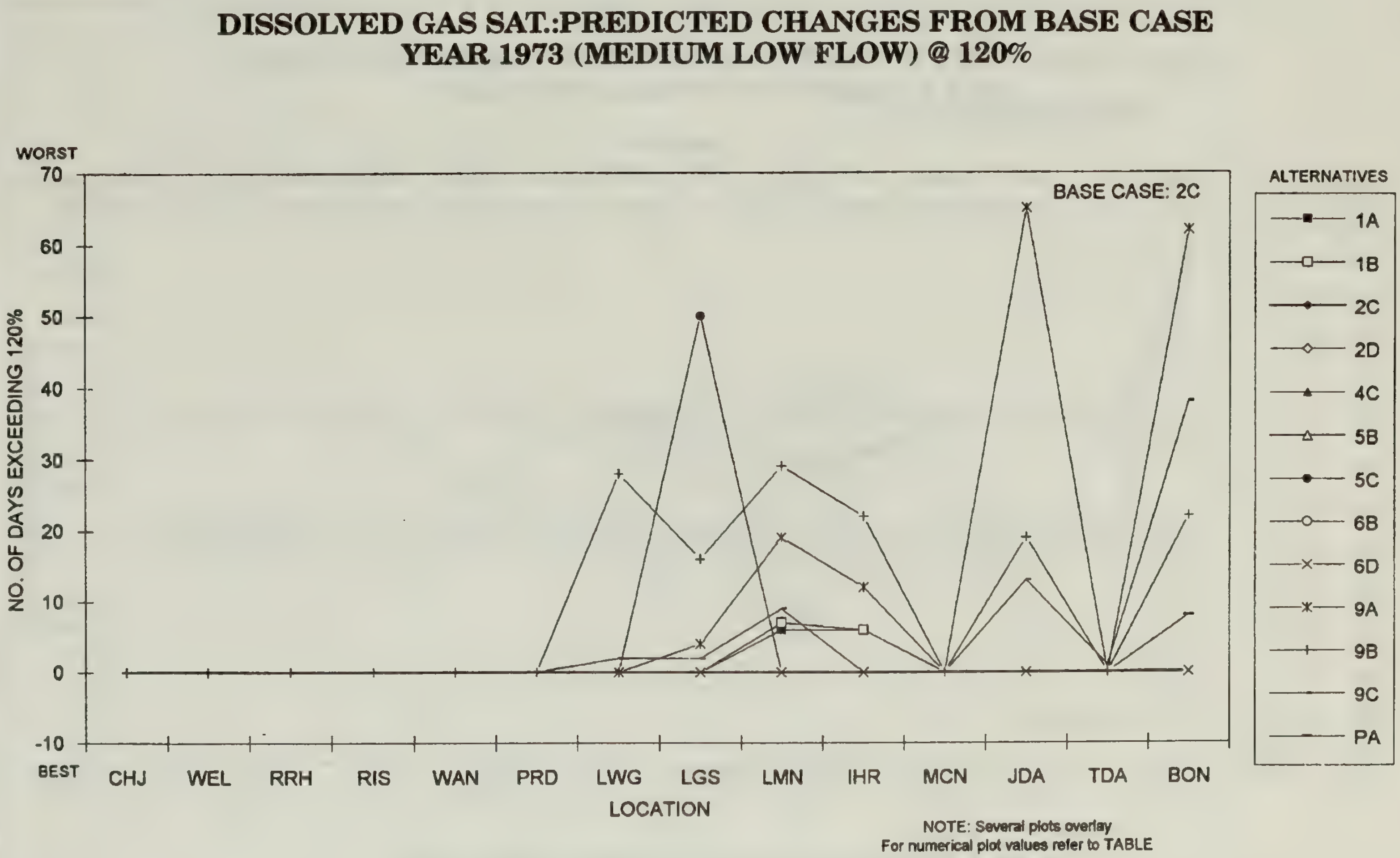
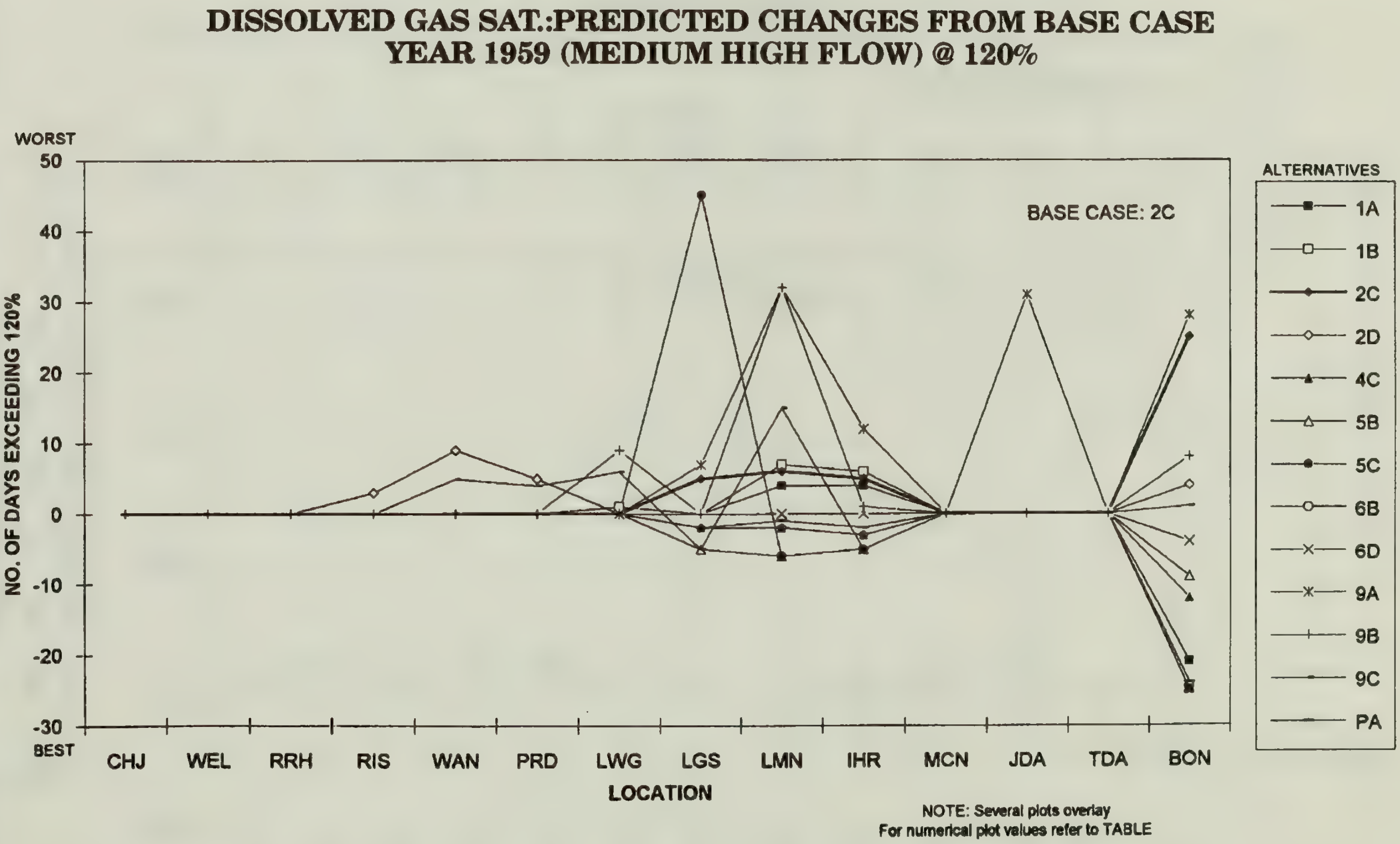


Figure D–16. Dissolved Gas Sat.:Predicted Changes from Base Case, 1973 (Medium Low Flow)



NOTE: Several plots overlay
For numerical plot values refer to TABLE

Figure D–17. Dissolved Gas Sat.:Predicted Changes from Base Case, 1959 (Medium High Flow)

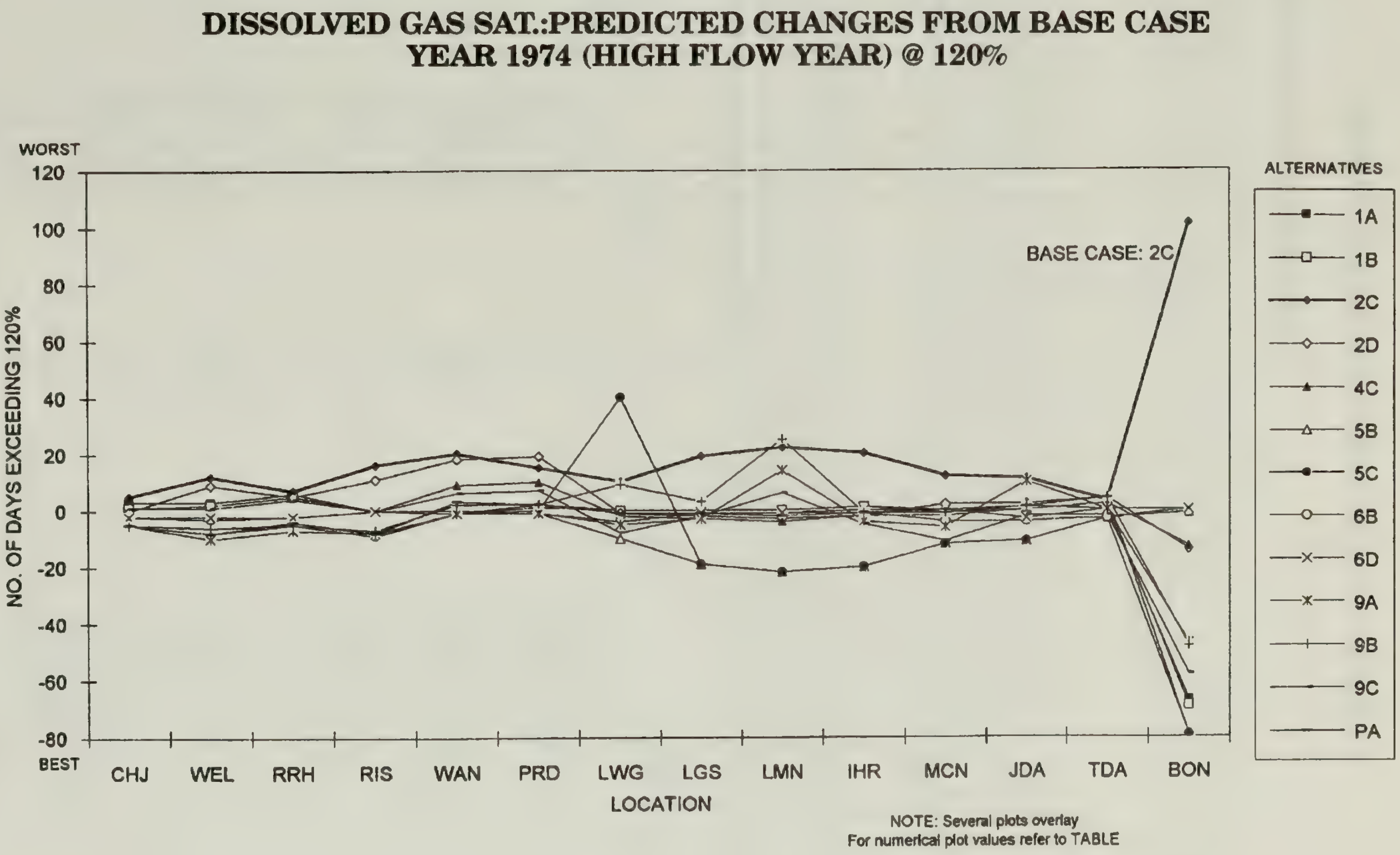


Figure D–18. Dissolved Gas Sat.:Predicted Changes from Base Case, 1974 (High Flow Year)

## TECHNICAL EXHIBIT E

## PREDICTED WATER TEMPERATURE PROFILES

### LIBBY AND HUNGRY HORSE RESERVOIRS

The results shown below were generated by the Resident Fish Work Group using a thermal model originally developed by Briane Adams of the U.S. Geological Survey. The model was run for the 1929–78 (50 years) period in the forebay of each of the two reservoirs. Results represent averaged quintiles: 80, 60, 40, 20, and 0 = highest 1/5th of water years through lowest 1/5th of water years. All profiles relate to August 15 model predictions.

For example, for alternative 1a, in the 10 highest (of the 50) flow years, the temperature at 30.4 meter depth is predicted to be 12.9 degrees C; in the lowest 10 flow years, the predicted temperature at that same depth is 10.2 degrees C. By re–arranging the quintiles in the form of an histogram, one can also generally deduce that predicted August 15 average water temperature at 30.4 meter depth is 10.2 degrees C or greater 100 percent of the time, 12.0 degrees C or greater 80 percent of the time, 12.9 degrees C or greater 60 percent of the time, 13.6 degrees C or greater 40 percent of the time, 14.5 degrees C or greater 20 percent of the time during the 50 year period.

The predicted 80 percent quintile water temperature profiles on August 15 for the 1929–78 period at Hungry Horse are shown in Figure E–1. Figures E–2 through E–6 show the predicted temperature of the release from Libby in relation to the optimum temperature range for fisheries. A set of figures are also given that provide predicted water temperature profiles for various reservoir depths at Hungry Horse and Libby Dams as listed below:

| Figure | File Name | Flow in % of Average | Prediction Date |
|---|---|---|---|
| Hungry Horse | | | |
| E–7 | grab.wpg | 86.4 | May 1, 1957 |
| E–8 | grab_1.wpg | 86.4 | August 15, 1957 |
| E–9 | grab_2.wpg | 86.4 | September 30, 1957 |
| E–10 | grab_3.wpg | 100.8 | May 1, 1969 |
| E–11 | grab_4.wpg | 100.8 | August 15, 1969 |
| E–12 | grab_5.wpg | 100.8 | September 30, 1969 |
| E–13 | grab_6.wpg | 115.1 | May 1, 1956 |
| E–14 | grab_7.wpg | 115.1 | August 15, 1956 |
| E–15 | grab_8.wpg | 115.1 | September 30, 1956 |
| Libby | | | |
| E–16 | grab.wpg | 115.7 | May 1, 1981 |
| E–17 | grab_1.wpg | 115.7 | August 15, 1981 |
| E–18 | grab_2.wpg | 115.7 | September 30, 1981 |
| E–19 | grab_3.wpg | 100.0 | May 1, 1983 |
| E–20 | grab_4.wpg | 100.0 | August 15, 1983 |
| E–21 | grab_5.wpg | 100.0 | September 30, 1983 |
| E–22 | grab_6.wpg | 85.7 | May 1, 1984 |
| E–23 | grab_7.wpg | 85.7 | August 15, 1984 |
| E–24 | grab_8.wpg | 85.7 | September 30, 1984 |

## Table E–1. Predicted Temperature Profiles for Libby Reservoir (Degrees C)

| Depth, Meters | 30.4 | 28.8 | 25.6 | 22.4 | 19.2 | 16.0 | 12.8 | 9.6 | 6.4 | 3.2 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alt. 1a | | | | | | | | | | | |
| 80%ile | 12.9 | 12.9 | 14.4 | 16.2 | 17.3 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 60%ile | 13.6 | 13.6 | 14.6 | 15.6 | 16.9 | 17.5 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 40%ile | 14.5 | 14.5 | 15.4 | 16.6 | 17.4 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 20%ile | 12.0 | 12.0 | 13.4 | 16.1 | 17.4 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 |
| 00%ile | 10.2 | 10.2 | 11.6 | 13.4 | 16.3 | 17.5 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 |
| Alt. 1b | | | | | | | | | | | |
| 80%ile | 12.6 | 12.6 | 14.2 | 16.2 | 17.3 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 60%ile | 13.5 | 13.5 | 14.4 | 15.6 | 17.0 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 40%ile | 14.6 | 14.6 | 15.5 | 16.7 | 17.5 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 20%ile | 11.8 | 11.8 | 13.4 | 16.3 | 17.5 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 |
| 00%ile | 10.7 | 10.7 | 11.8 | 13.3 | 15.7 | 17.4 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 |
| Alt. 2a | | | | | | | | | | | |
| 80%ile | 14.4 | 14.4 | 16.3 | 17.3 | 17.6 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 60%ile | 13.9 | 13.9 | 14.7 | 16.1 | 17.3 | 17.6 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 |
| 40%ile | 13.9 | 13.9 | 15.0 | 15.8 | 16.7 | 17.4 | 17.6 | 17.7 | 17.8 | 17.8 | 17.8 |
| 20%ile | 12.6 | 12.6 | 14.6 | 16.8 | 17.6 | 17.7 | 17.8 | 17.8 | 17.9 | 17.9 | 17.9 |
| 00%ile | 10.7 | 10.7 | 11.9 | 13.8 | 16.8 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |
| Alt. 2b | | | | | | | | | | | |
| 80%ile | 13.4 | 13.4 | 15.0 | 16.9 | 17.5 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 60%ile | 14.3 | 14.3 | 15.6 | 17.1 | 17.5 | 17.6 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 |
| 40%ile | 12.2 | 12.2 | 13.4 | 15.8 | 17.3 | 17.7 | 17.8 | 17.8 | 17.9 | 17.9 | 17.9 |
| 20%ile | 10.4 | 10.4 | 12.2 | 15.0 | 17.2 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |
| 00%ile | 9.6 | 9.6 | 11.8 | 14.1 | 16.7 | 17.5 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| Alt. 3a | | | | | | | | | | | |
| 80%ile | 13.4 | 13.4 | 15.0 | 16.9 | 17.5 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 60%ile | 14.3 | 14.3 | 15.6 | 17.1 | 17.5 | 17.6 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 |
| 40%ile | 12.2 | 12.2 | 13.4 | 15.8 | 17.3 | 17.7 | 17.8 | 17.8 | 17.9 | 17.9 | 17.9 |
| 20%ile | 10.4 | 10.4 | 12.2 | 15.0 | 17.2 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |
| 00%ile | 9.1 | 9.1 | 11.5 | 13.3 | 16.1 | 17.5 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |
| Alt. 4a1 | | | | | | | | | | | |
| 80%ile | 13.4 | 13.4 | 15.0 | 16.9 | 17.5 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 60%ile | 14.3 | 14.3 | 15.6 | 17.1 | 17.5 | 17.6 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 |
| 40%ile | 12.1 | 12.1 | 13.3 | 15.8 | 17.3 | 17.7 | 17.8 | 17.8 | 17.9 | 17.9 | 17.9 |
| 20%ile | 10.4 | 10.4 | 12.2 | 15.0 | 17.2 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |
| 00%ile | 9.1 | 9.1 | 11.5 | 13.3 | 16.1 | 17.5 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |
| Alt. 4a3 | | | | | | | | | | | |
| 80%ile | 12.6 | 12.6 | 13.9 | 15.6 | 17.2 | 17.6 | 17.6 | 17.7 | 17.8 | 17.8 | 17.8 |
| 60%ile | 13.1 | 13.1 | 14.3 | 16.3 | 17.5 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 |
| 40%ile | 10.9 | 10.9 | 12.6 | 14.7 | 16.9 | 17.6 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 |
| 20%ile | 10.9 | 10.9 | 13.2 | 16.4 | 17.6 | 17.8 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |
| 00%ile | 11.0 | 11.0 | 13.0 | 15.6 | 17.2 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |

## Table E–1. Predicted Temperature Profiles for Libby Reservoir (Degrees C) – CONT

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alt. 4b3 | | | | | | | | | | | |
| 80%ile | 11.9 | 11.9 | 13.3 | 15.4 | 17.1 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 60%ile | 12.9 | 12.9 | 14.1 | 16.3 | 17.5 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 |
| 40%ile | 10.8 | 10.8 | 12.4 | 14.6 | 16.9 | 17.6 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 |
| 20%ile | 10.9 | 10.9 | 13.2 | 16.4 | 17.6 | 17.8 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |
| 00%ile | 11.0 | 11.0 | 13.0 | 15.6 | 17.2 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 | 17.9 |
| Alt. 6b | | | | | | | | | | | |
| 80%ile | 12.9 | 12.9 | 14.4 | 16.2 | 17.3 | 17.6 | 17.7 | 17.7 | 17.8 | 17.8 | 17.8 |
| 60%ile | 13.2 | 13.2 | 14.4 | 15.3 | 16.4 | 17.3 | 17.5 | 17.6 | 17.7 | 17.7 | 17.7 |
| 40%ile | 14.2 | 14.2 | 15.1 | 16.2 | 17.2 | 17.6 | 17.6 | 17.7 | 17.8 | 17.8 | 17.8 |
| 20%ile | 12.3 | 12.3 | 13.7 | 16.0 | 17.3 | 17.6 | 17.7 | 17.8 | 17.8 | 17.8 | 17.8 |
| 00%ile | 10.2 | 10.2 | 11.6 | 13.3 | 16.2 | 17.5 | 17.7 | 17.8 | 17.9 | 17.9 | 17.9 |

## Table E–2. Temperature Profiles for Hungry Horse Reservoir (Degrees C)

| Depth, Meters | 45.0 | 40.0 | 36.0 | 31.0 | 27.0 | 22.0 | 18.0 | 13.0 | 9.0 | 4.0 | 0.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alt. 1a | | | | | | | | | | | |
| 80%ile | 8.5 | 9.5 | 10.3 | 11.1 | 11.9 | 12.8 | 13.9 | 15.2 | 16.7 | 20.1 | 20.4 |
| 60%ile | 5.2 | 6.6 | 8.1 | 9.4 | 10.4 | 11.5 | 12.8 | 14.4 | 16.3 | 20.5 | 20.5 |
| 40%ile | 4.4 | 5.5 | 7.3 | 9.0 | 10.2 | 11.4 | 12.8 | 14.5 | 16.4 | 20.5 | 20.5 |
| 20%ile | 4.1 | 4.6 | 5.7 | 7.5 | 9.0 | 10.3 | 11.7 | 13.6 | 16.2 | 20.6 | 20.6 |
| 00%ile | 4.5 | 5.2 | 6.3 | 7.8 | 9.2 | 10.6 | 12.0 | 13.9 | 16.4 | 19.7 | 20.4 |
| 1974 | 9.2 | 10.3 | 11.3 | 12.1 | 12.8 | 13.3 | 14.1 | 15.3 | 16.7 | 19.9 | 20.4 |
| 1941 | 4.0 | 4.1 | 4.5 | 5.1 | 6.3 | 8.0 | 10.1 | 12.7 | 15.8 | 19.4 | 20.4 |
| Alt. 1b | | | | | | | | | | | |
| 80%ile | 8.6 | 9.5 | 10.3 | 11.1 | 11.9 | 12.8 | 13.9 | 15.2 | 16.7 | 20.0 | 20.4 |
| 60%ile | 5.2 | 6.6 | 8.1 | 9.4 | 10.5 | 11.6 | 12.8 | 14.4 | 16.3 | 20.5 | 20.5 |
| 40%ile | 4.8 | 6.2 | 8.0 | 9.4 | 10.6 | 11.7 | 13.2 | 14.8 | 17.0 | 20.7 | 20.7 |
| 20%ile | 4.1 | 4.6 | 6.0 | 7.8 | 9.2 | 10.3 | 11.6 | 13.5 | 16.0 | 20.6 | 20.6 |
| 00%ile | 5.0 | 6.1 | 7.6 | 8.9 | 10.0 | 11.2 | 12.8 | 14.8 | 17.6 | 20.5 | 20.5 |
| 1974 | 9.2 | 10.3 | 11.3 | 12.1 | 12.8 | 13.3 | 14.1 | 15.3 | 16.7 | 19.9 | 20.4 |
| 1941 | 4.0 | 4.2 | 5.0 | 6.4 | 8.1 | 9.5 | 11.1 | 13.3 | 16.5 | 20.7 | 20.7 |
| Alt. 2a (= alt. 2b, c) | | | | | | | | | | | |
| 80%ile | 8.2 | 9.3 | 10.1 | 11.0 | 11.9 | 12.9 | 14.0 | 15.2 | 16.7 | 20.1 | 20.4 |
| 60%ile | 5.7 | 7.2 | 8.6 | 9.7 | 10.6 | 11.7 | 13.0 | 14.7 | 16.7 | 20.7 | 20.7 |
| 40%ile | 4.5 | 5.6 | 7.4 | 9.0 | 10.3 | 11.5 | 12.9 | 14.6 | 16.7 | 20.6 | 20.6 |
| 20%ile | 4.2 | 4.7 | 6.0 | 7.8 | 9.2 | 10.4 | 11.8 | 13.7 | 16.4 | 20.6 | 20.6 |
| 00%ile | 4.3 | 4.9 | 5.8 | 7.2 | 8.8 | 10.3 | 11.9 | 13.9 | 16.4 | 19.8 | 20.4 |
| 1974 | 9.4 | 10.4 | 11.4 | 12.2 | 12.9 | 13.4 | 14.1 | 15.2 | 16.7 | 20.0 | 20.4 |
| 1941 | 4.0 | 4.0 | 4.2 | 4.7 | 5.8 | 7.6 | 10.1 | 13.1 | 16.6 | 19.9 | 20.3 |

## Table E–2. Temperature Profiles for Hungry Horse Reservoir (Degrees C) – CONT

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Alt. 3a (= alt. 3b) | | | | | | | | | | | |
| 80%ile | 8.2 | 9.3 | 10.1 | 11.0 | 11.9 | 12.9 | 14.0 | 15.2 | 16.7 | 20.1 | 20.4 |
| 60%ile | 5.7 | 7.2 | 8.6 | 9.7 | 10.6 | 11.7 | 13.0 | 14.7 | 16.7 | 20.7 | 20.7 |
| 40%ile | 4.5 | 5.6 | 7.4 | 9.0 | 10.3 | 11.5 | 12.9 | 14.6 | 16.7 | 20.6 | 20.6 |
| 20%ile | 4.2 | 4.7 | 6.0 | 7.8 | 9.2 | 10.4 | 11.8 | 13.7 | 16.4 | 20.6 | 20.6 |
| 00%ile | 4.3 | 4.9 | 5.8 | 7.2 | 8.8 | 10.3 | 11.9 | 13.9 | 16.4 | 19.8 | 20.4 |
| 1974 | 9.4 | 10.4 | 11.4 | 12.2 | 12.9 | 13.4 | 14.1 | 15.2 | 16.7 | 20.0 | 20.4 |
| 1941 | 4.0 | 4.0 | 4.2 | 4.7 | 5.8 | 7.6 | 10.1 | 13.1 | 16.6 | 19.9 | 20.3 |
| Alt. 4a1 (= alt. 4b1) | | | | | | | | | | | |
| 80%ile | 8.1 | 9.3 | 10.2 | 11.0 | 11.9 | 12.9 | 13.9 | 15.2 | 16.7 | 20.3 | 20.4 |
| 60%ile | 5.3 | 6.6 | 8.0 | 9.3 | 10.4 | 11.5 | 12.8 | 14.4 | 16.3 | 20.5 | 20.5 |
| 40%ile | 4.3 | 4.8 | 5.8 | 7.3 | 9.0 | 10.7 | 12.3 | 14.0 | 16.1 | 20.4 | 20.4 |
| 20%ile | 4.1 | 4.4 | 5.0 | 6.1 | 7.6 | 9.3 | 10.9 | 12.9 | 15.4 | 20.5 | 20.5 |
| 00%ile | 4.0 | 4.0 | 4.0 | 4.3 | 5.0 | 6.6 | 9.0 | 11.7 | 14.8 | 20.5 | 20.5 |
| 1974 | 9.3 | 10.4 | 11.4 | 12.2 | 12.9 | 13.4 | 14.1 | 15.2 | 16.7 | 20.0 | 20.4 |
| 1941 | 4.0 | 4.0 | 4.0 | 4.0 | 4.1 | 4.6 | 6.4 | 9.9 | 14.2 | 20.6 | 20.6 |
| Alt. 4a3 (= alt. 4b3) | | | | | | | | | | | |
| 80%ile | 7.8 | 8.9 | 9.9 | 10.9 | 11.8 | 12.8 | 13.8 | 15.1 | 16.7 | 20.3 | 20.4 |
| 60%ile | 5.4 | 6.4 | 7.7 | 9.0 | 10.3 | 11.5 | 12.8 | 14.3 | 16.2 | 20.5 | 20.5 |
| 40%ile | 4.4 | 5.0 | 6.1 | 7.5 | 9.1 | 10.7 | 12.3 | 14.1 | 16.1 | 20.4 | 20.4 |
| 20%ile | 4.1 | 4.3 | 4.9 | 5.9 | 7.3 | 9.0 | 10.7 | 12.7 | 15.2 | 20.5 | 20.5 |
| 00%ile | 4.0 | 4.0 | 4.0 | 4.3 | 5.0 | 6.6 | 9.0 | 11.7 | 14.8 | 20.5 | 20.5 |
| 1974 | 9.2 | 10.3 | 11.2 | 11.9 | 12.6 | 13.2 | 14.0 | 15.1 | 16.7 | 20.0 | 20.4 |
| 1941 | 4.0 | 4.0 | 4.0 | 4.0 | 4.1 | 4.6 | 6.4 | 9.9 | 14.2 | 20.6 | 20.6 |
| Alt. 5a (=alts. 5b, 6a b, c, d) | | | | | | | | | | | |
| 80%ile | 8.5 | 9.5 | 10.3 | 11.1 | 11.9 | 12.9 | 13.9 | 15.2 | 16.7 | 20.1 | 20.4 |
| 60%ile | 5.5 | 7.0 | 8.5 | 9.5 | 10.4 | 11.4 | 12.8 | 14.4 | 16.4 | 20.5 | 20.5 |
| 40%ile | 4.8 | 6.2 | 8.0 | 9.4 | 10.5 | 11.7 | 13.1 | 14.8 | 17.0 | 20.7 | 20.7 |
| 20%ile | 4.1 | 4.6 | 5.8 | 7.6 | 9.1 | 10.3 | 11.7 | 13.6 | 16.2 | 20.6 | 20.6 |
| 00%ile | 4.5 | 5.2 | 6.3 | 7.8 | 9.2 | 10.6 | 12.0 | 13.9 | 16.4 | 19.7 | 20.4 |
| 1974 | 9.1 | 10.2 | 11.2 | 12.1 | 12.8 | 13.5 | 14.2 | 15.3 | 16.7 | 19.7 | 20.4 |
| 1941 | 4.0 | 4.1 | 4.5 | 5.1 | 6.3 | 8.0 | 10.1 | 12.7 | 15.8 | 19.4 | 20.4 |

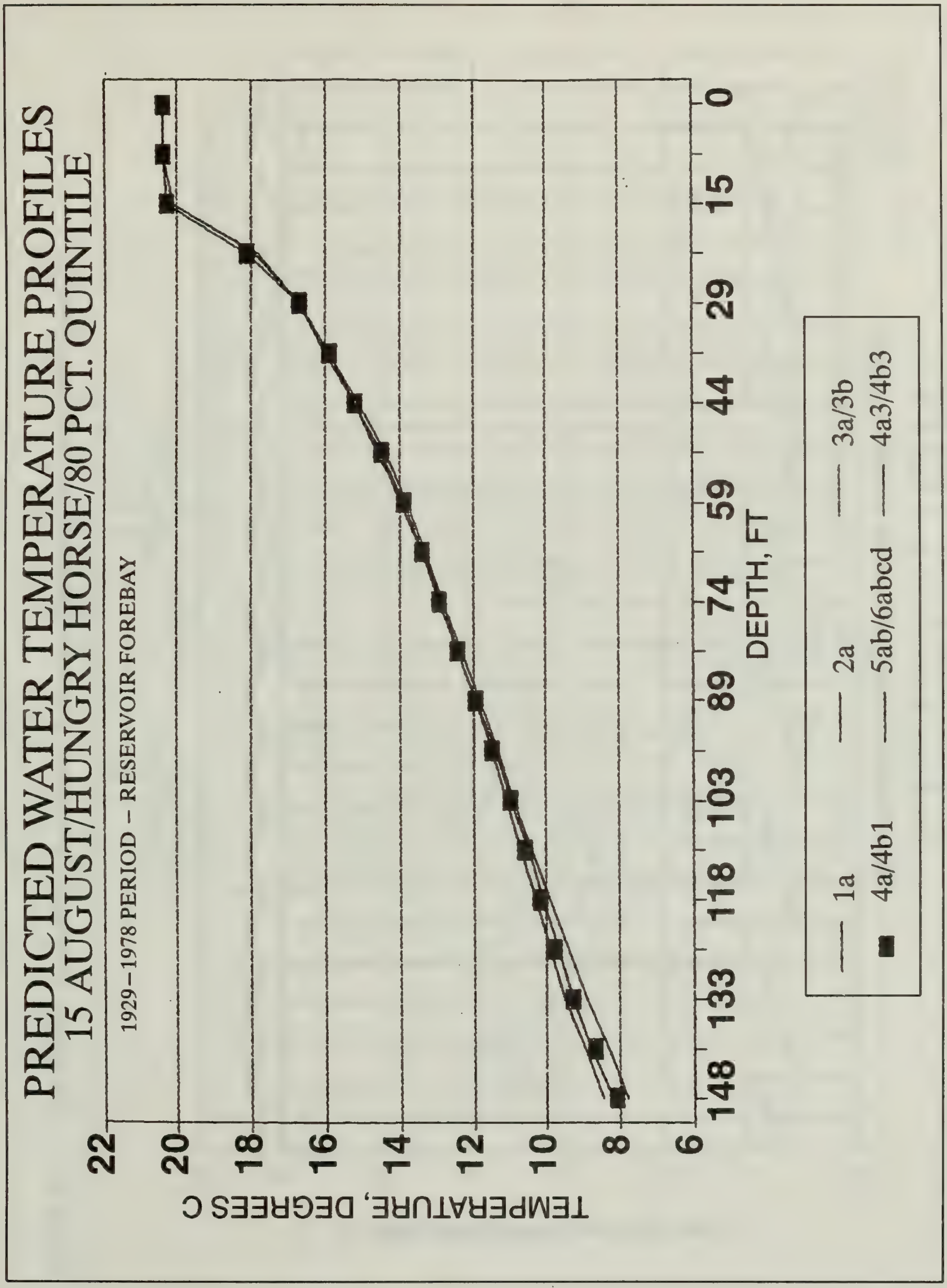


Figure E–1. Predicted Water Temperature Profiles

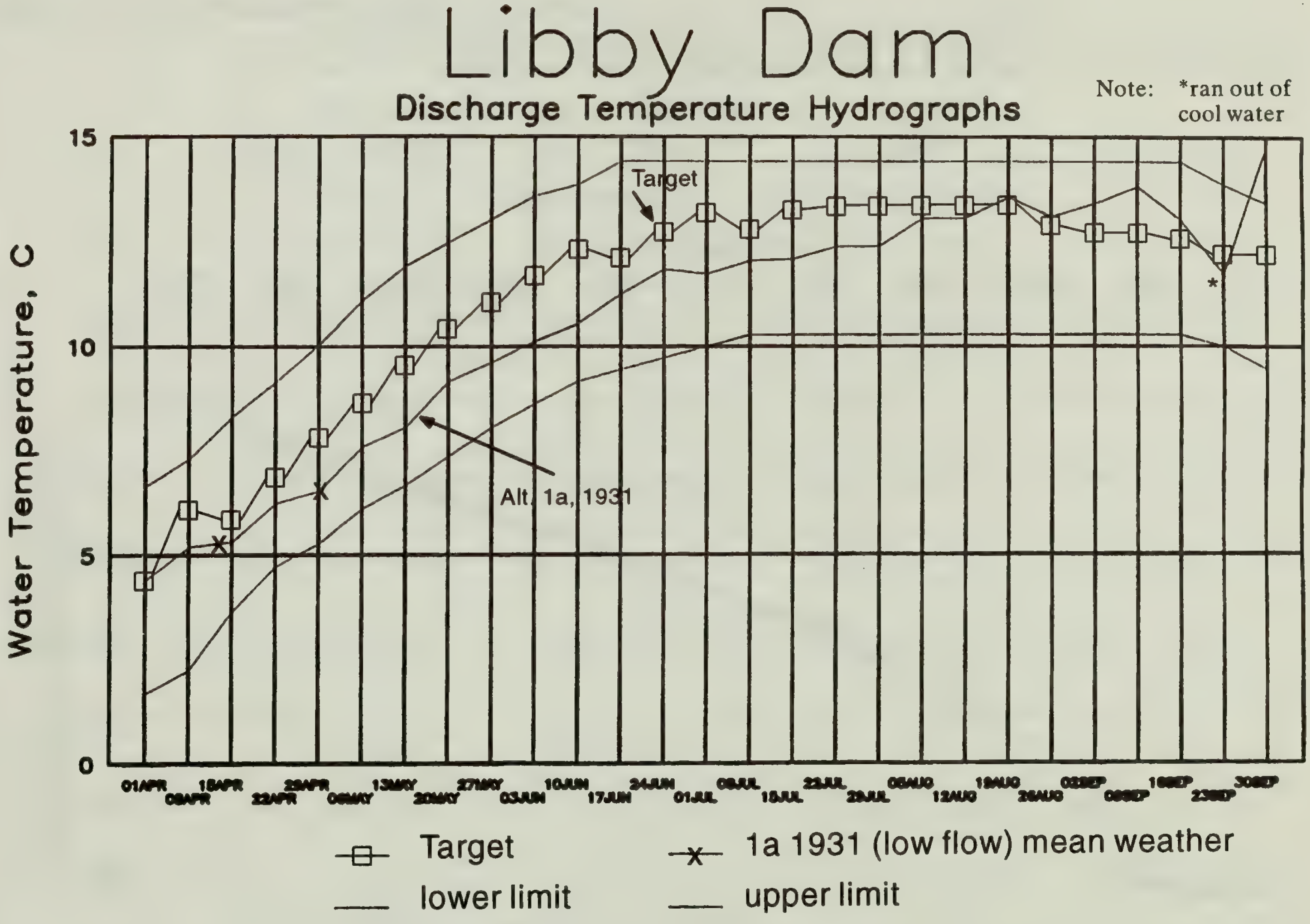


Figure E–2. Libby Dam Discharge Temperature Hydrographs, Alt. 1a 1931 Mean Weather

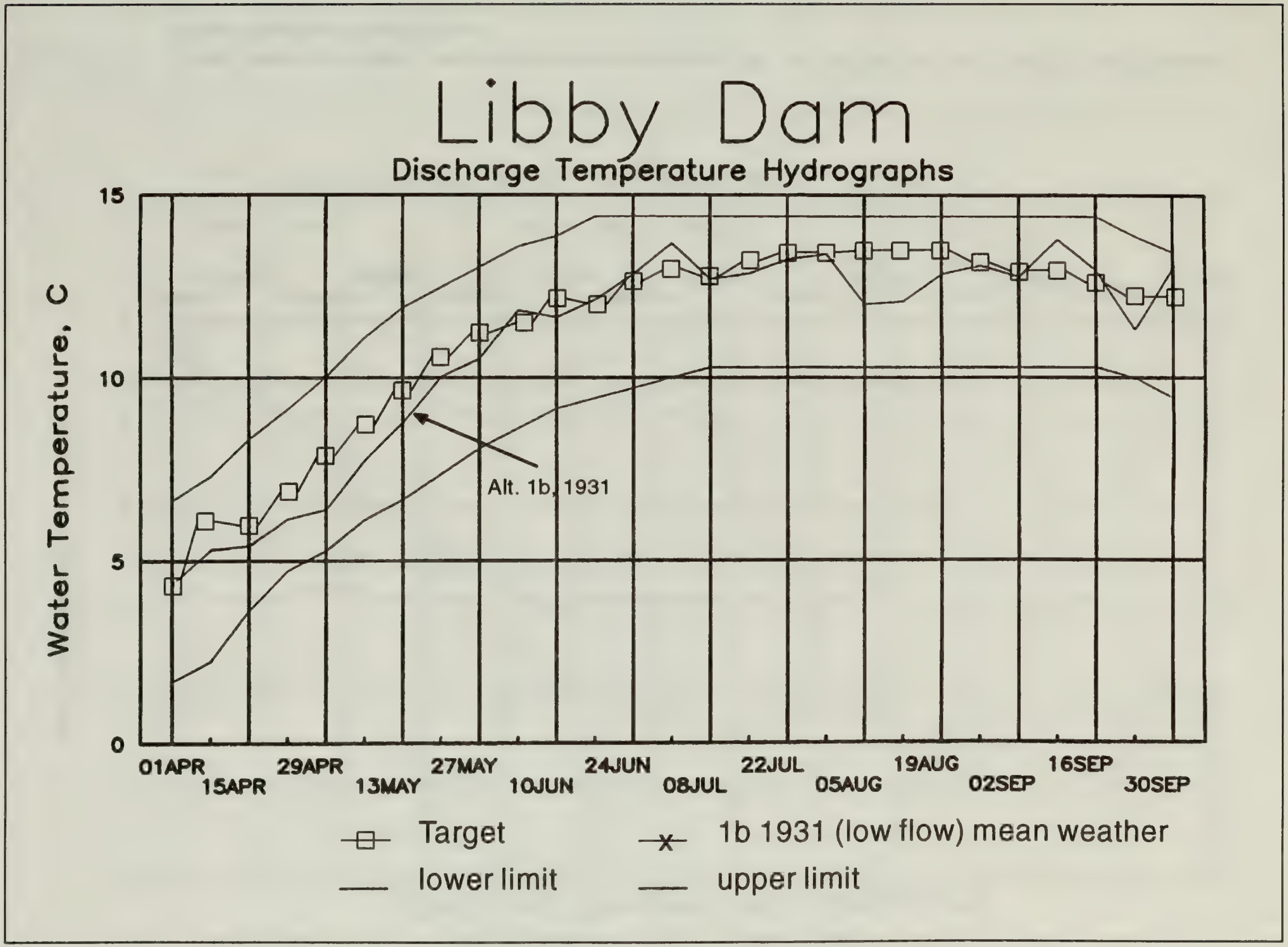


Figure E–3. Libby Dam Discharge Temperature Hydrographs, Alt. 1b 1931 (Low Flow) Mean Weather

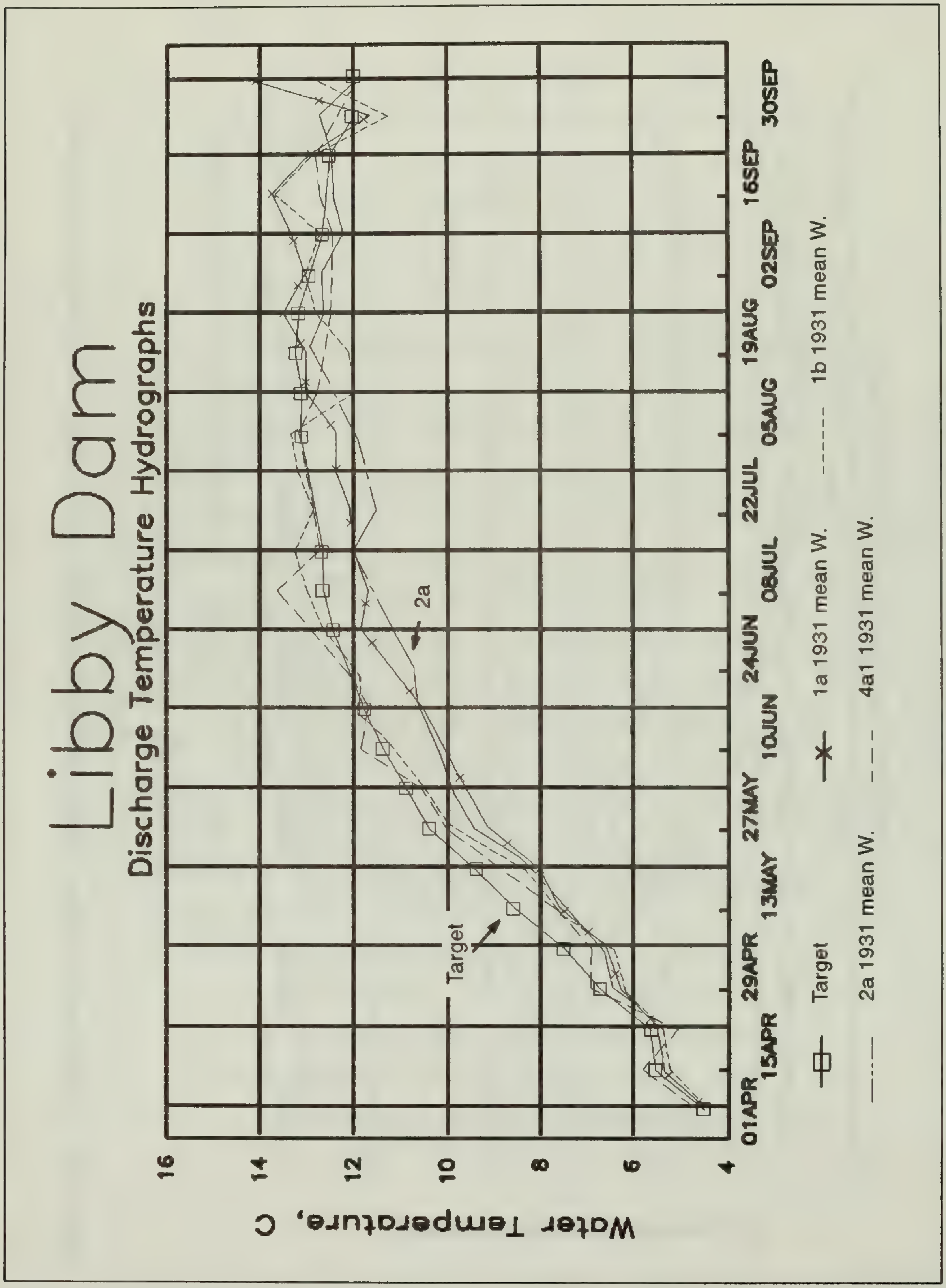


Figure E-4. Libby Dam Discharge Temperature Hydrographs, Alt. 1a, 1b, 2a and 4a1; 1931 (Low Flow) and Mean Weather Conditions

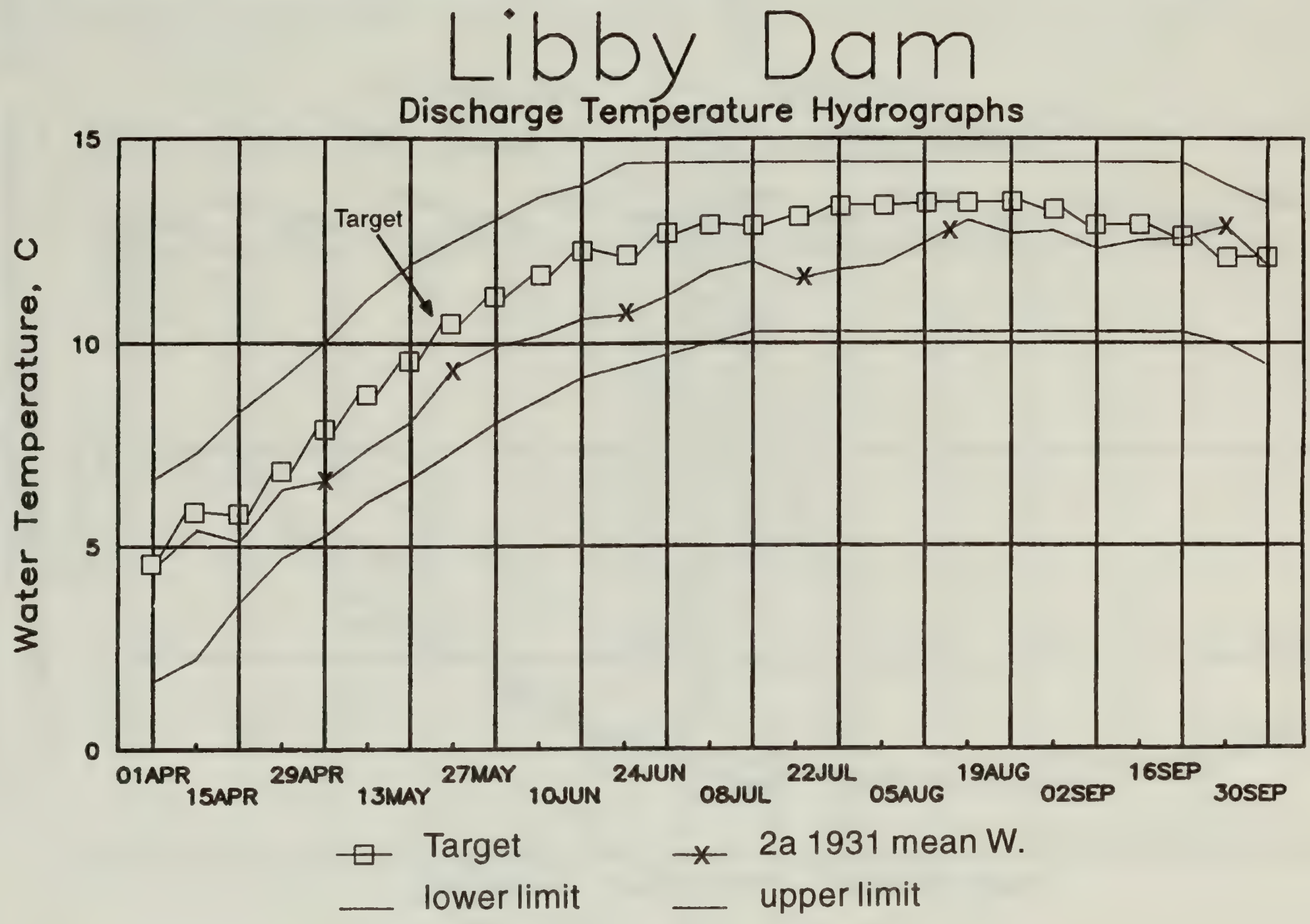


Figure E–5. Libby Dam Discharge Temperature Hydrographs, Alt. 2a 1931 (Low Flow) Mean Weather

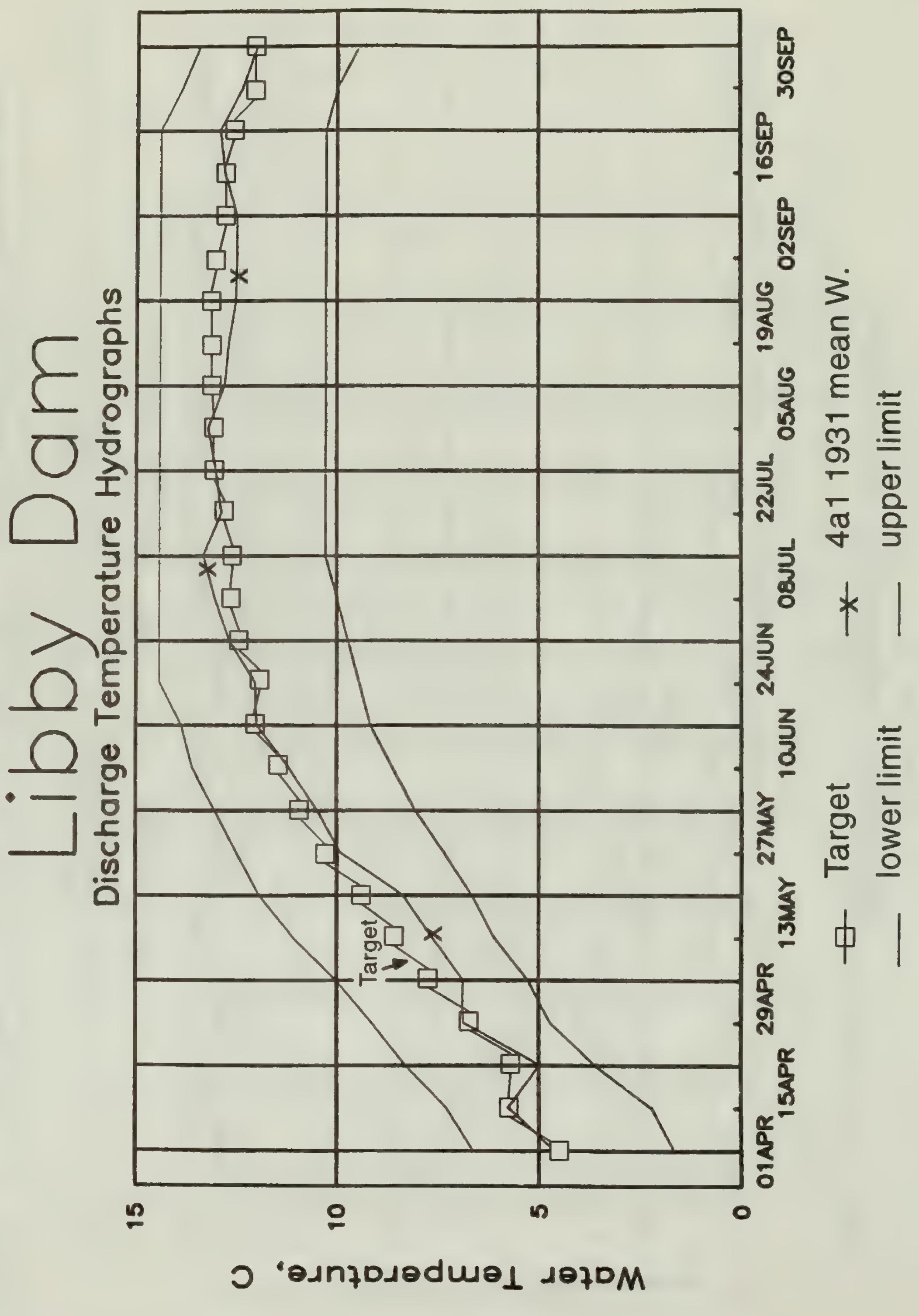


**Figure E–6.** Libby Dam Discharge Temperature Hydrographs, Alt. 4a1 1931 (Low Flow) Mean Weather

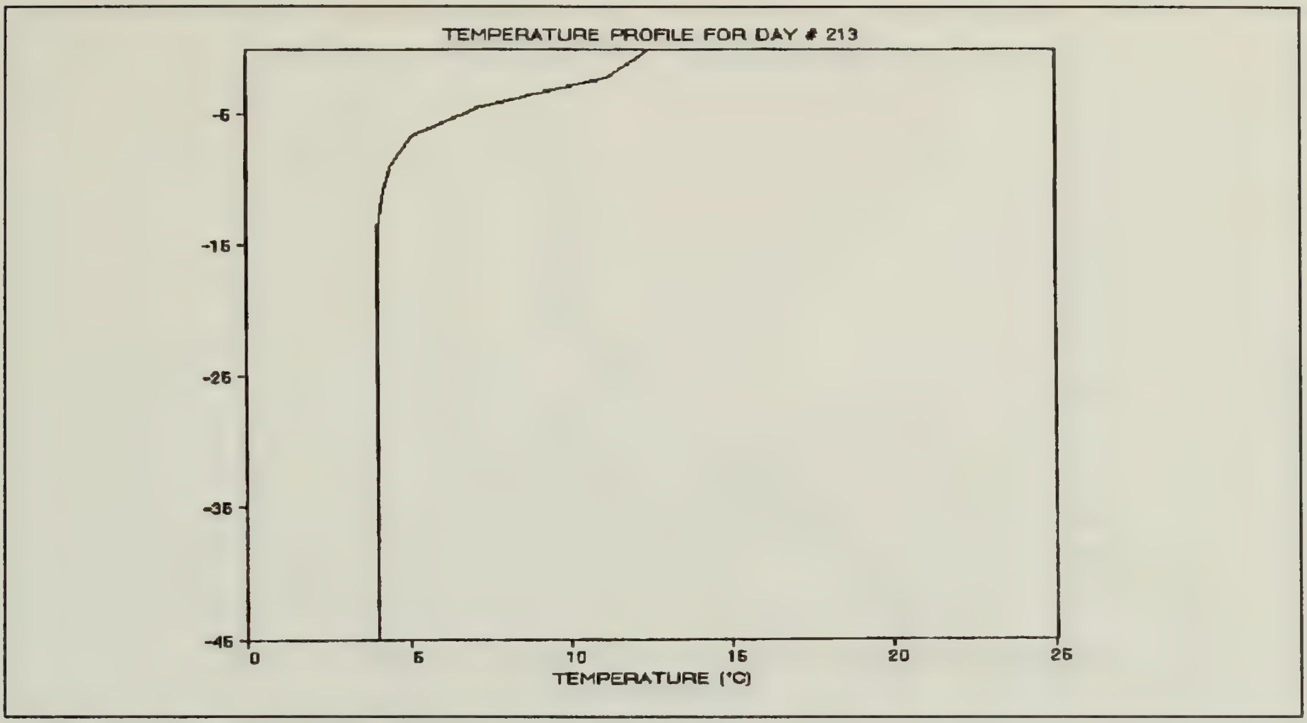


**Figure E–7.** **Predicted Water Temperature Profile Hungry Horse, May 1, 1957 (Below Average Flow)**

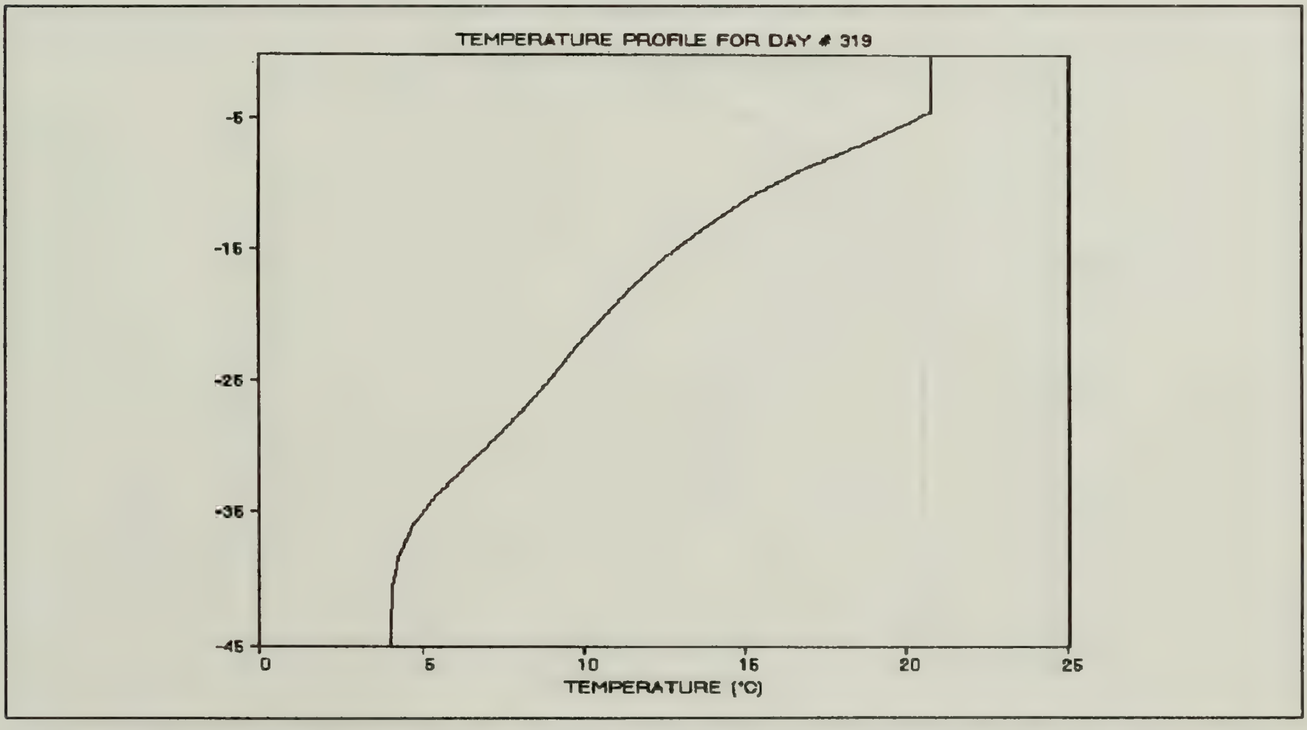


**Figure E–8.** **Predicted Water Temperature Profile Hungry Horse, August 15, 1957 (Below Average Flow)**

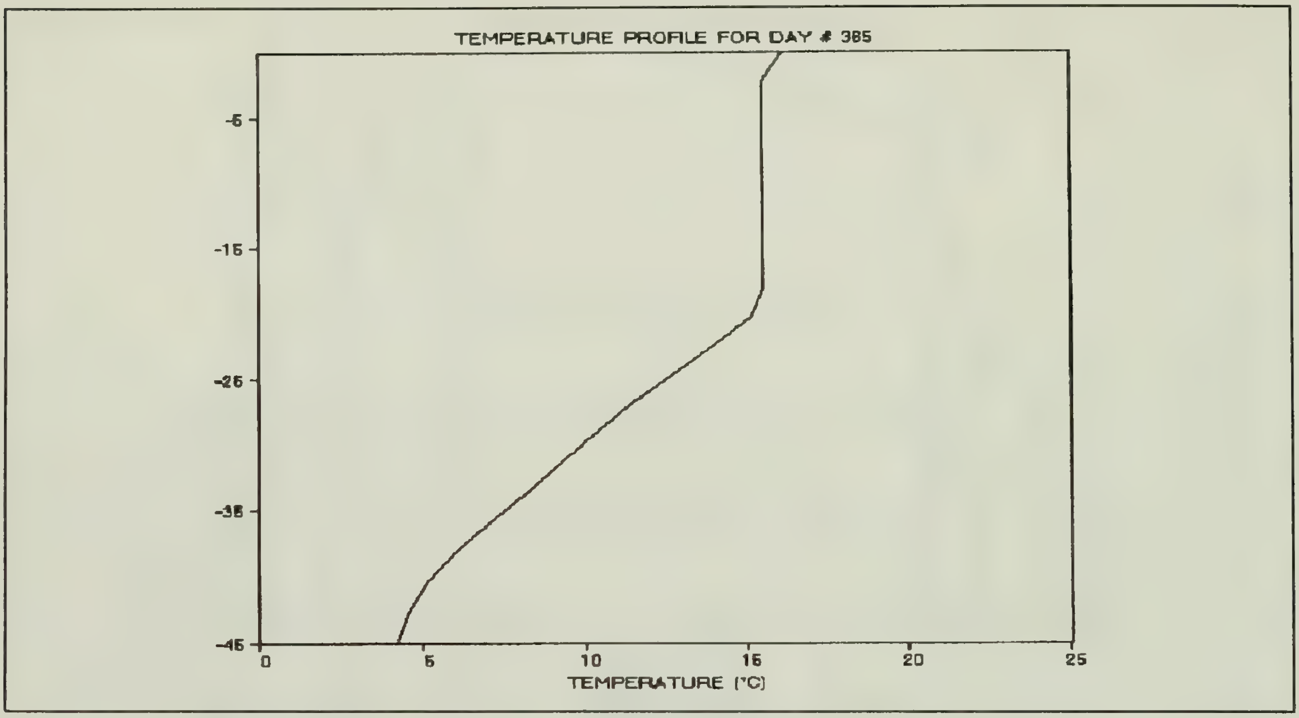


**Figure E–9.** Predicted Water Temperature Profile Hungry Horse, September 30, 1957 (Below Average Flow)

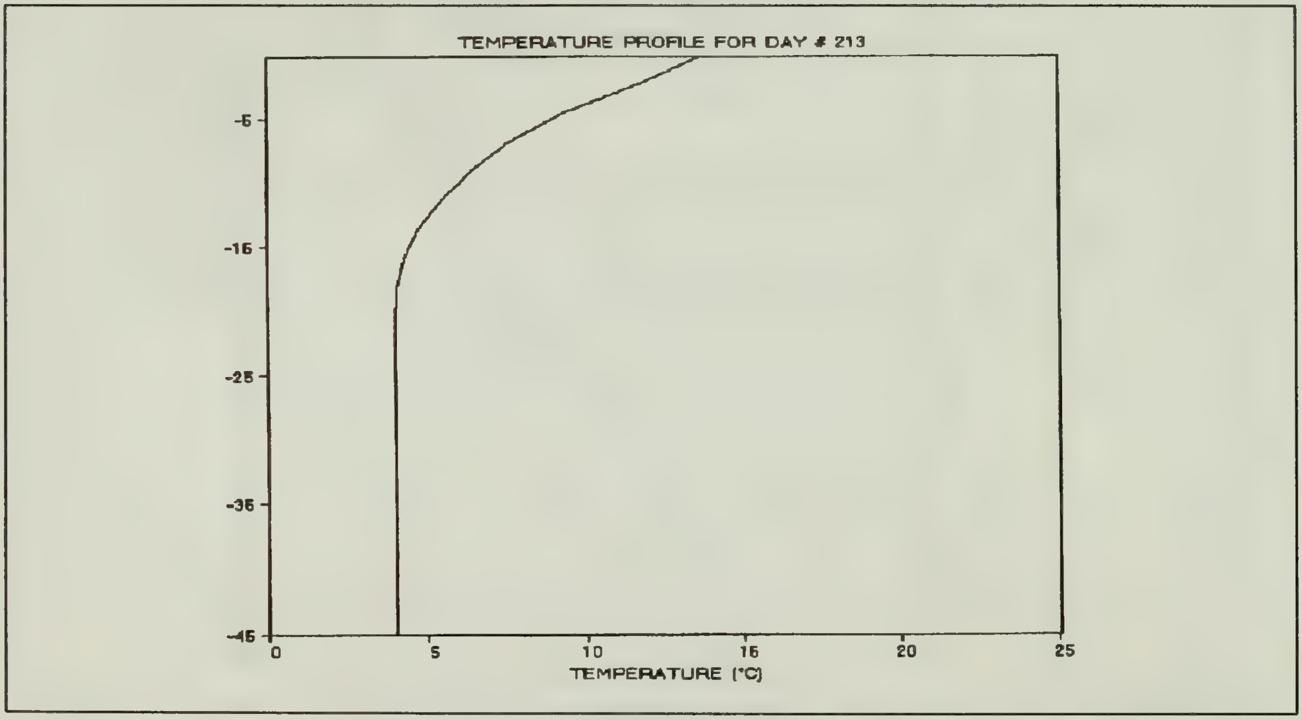


**Figure E–10.** Predicted Water Temperature Profile Hungry Horse, May 1, 1957 (Average Flow)

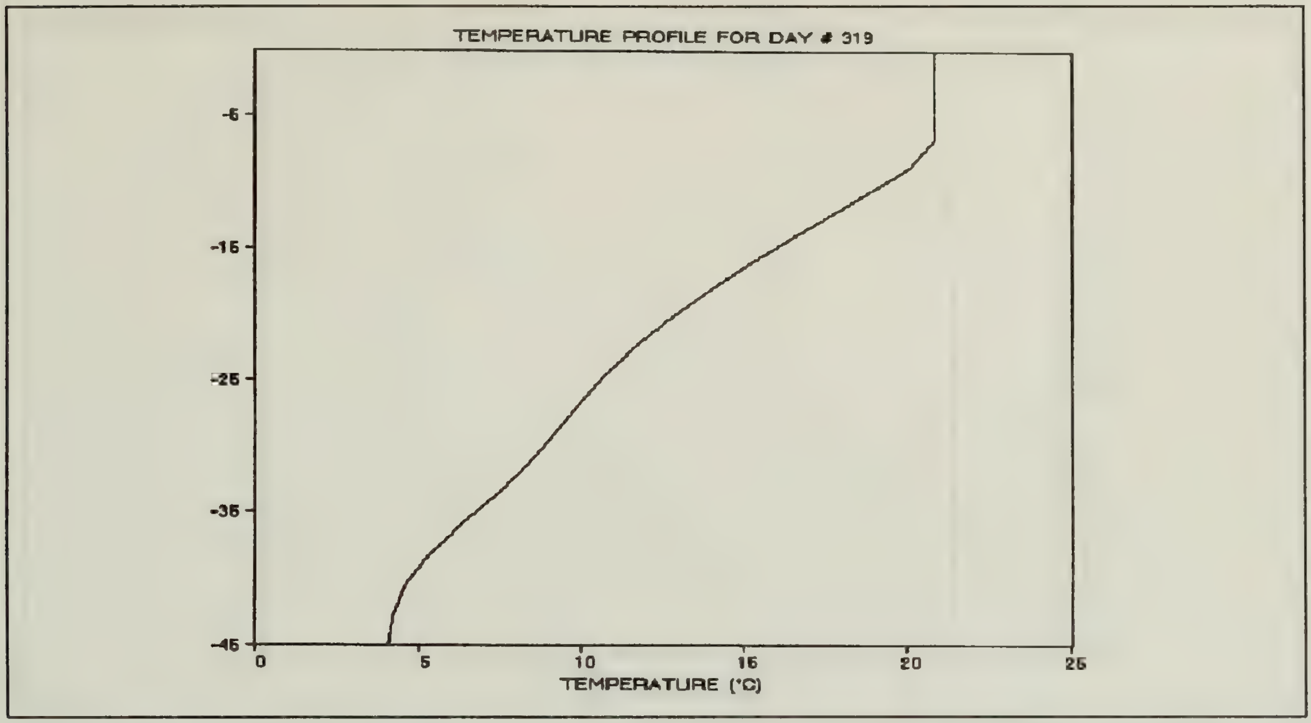


**Figure E-11.** **Predicted Water Temperature Profile Hungry Horse, August 15, 1969 (Average Flow)**

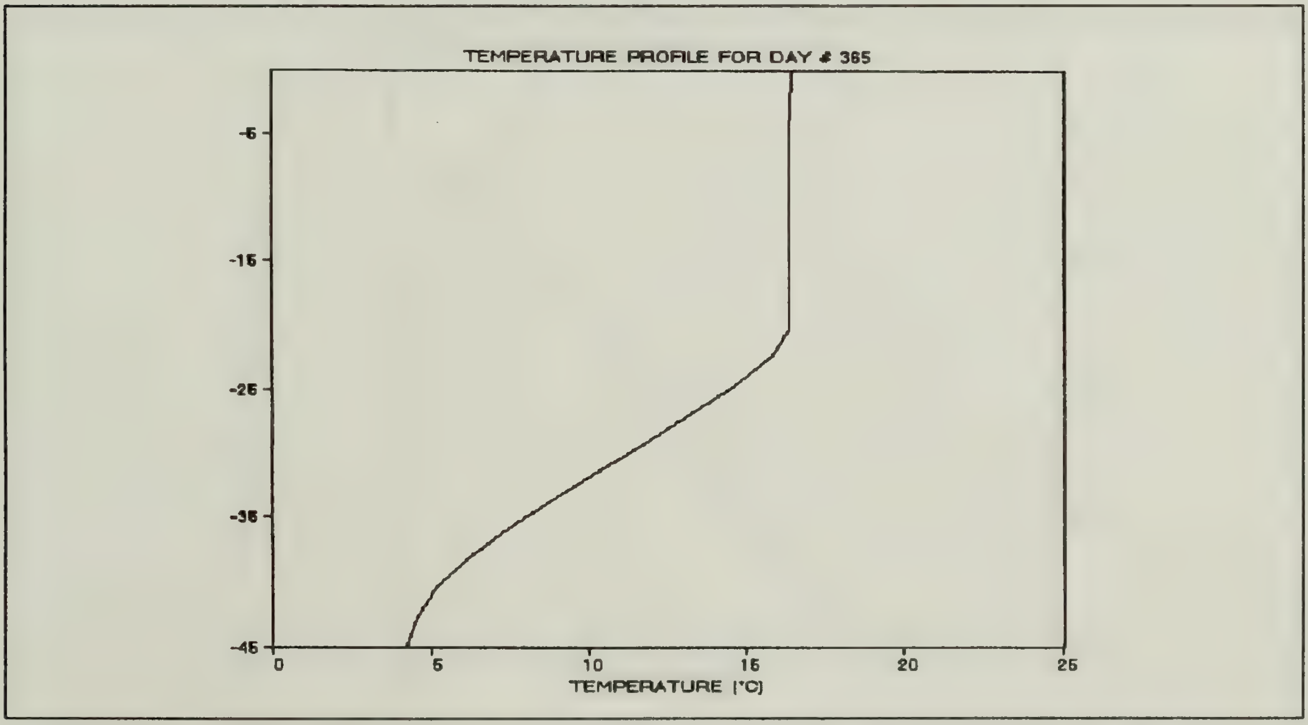


**Figure E-12.** **Predicted Water Temperature Profile Hungry Horse, September 30, 1969 (Average Flow)**

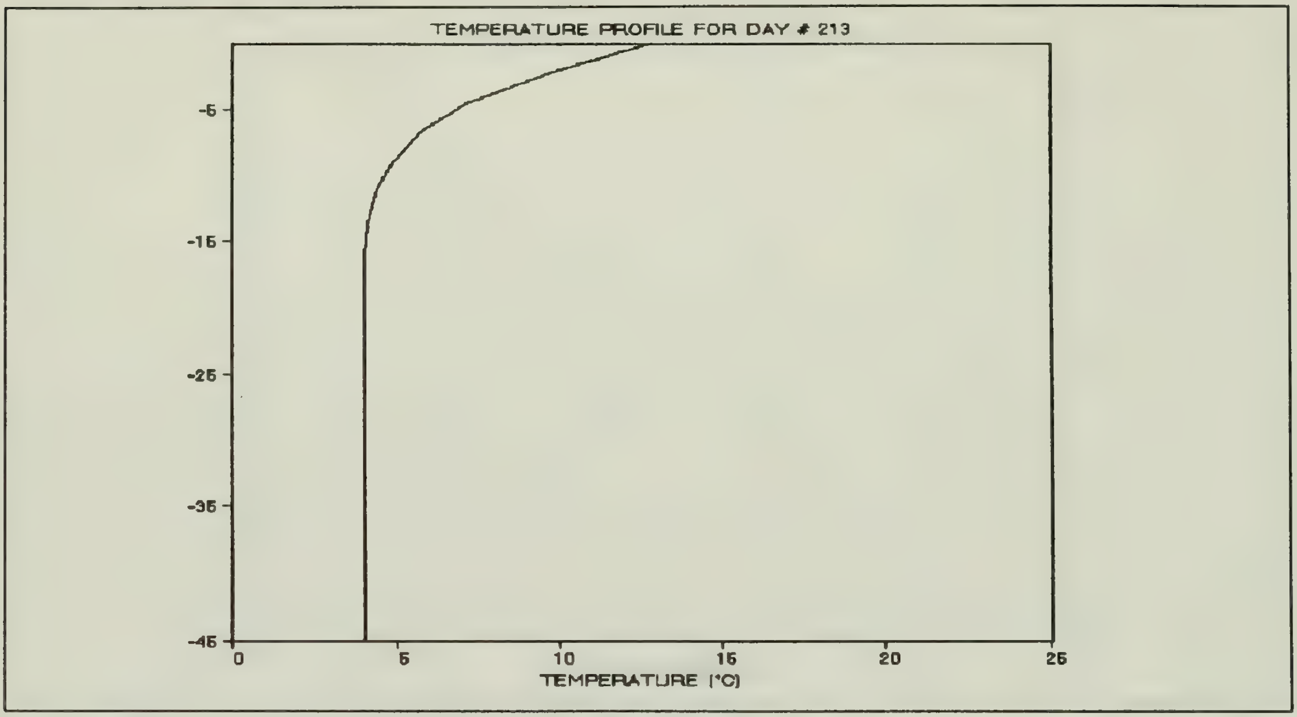


**Figure E–13. Predicted Water Temperature Profile Hungry Horse, May 1, 1956 (Above Average Flow)**

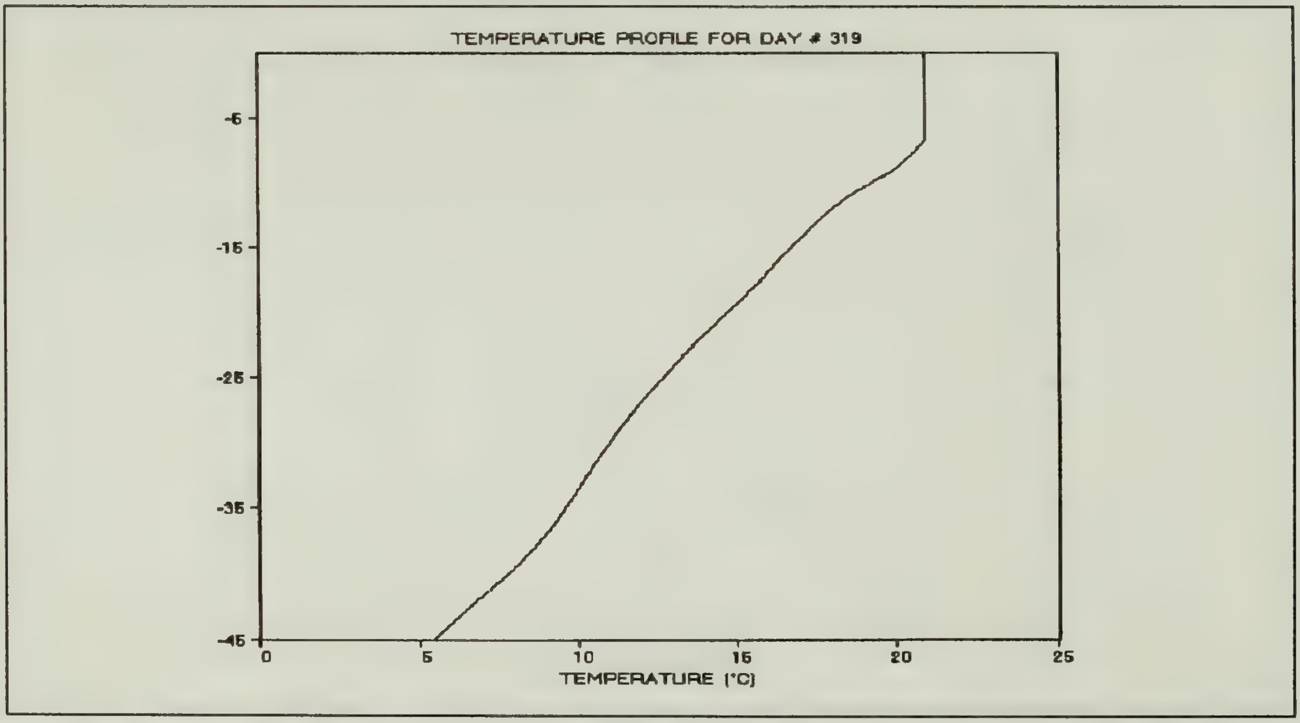


**Figure E–14. Predicted Water Temperature Profile Hungry Horse, August 15, 1957 (Above Average Flow)**

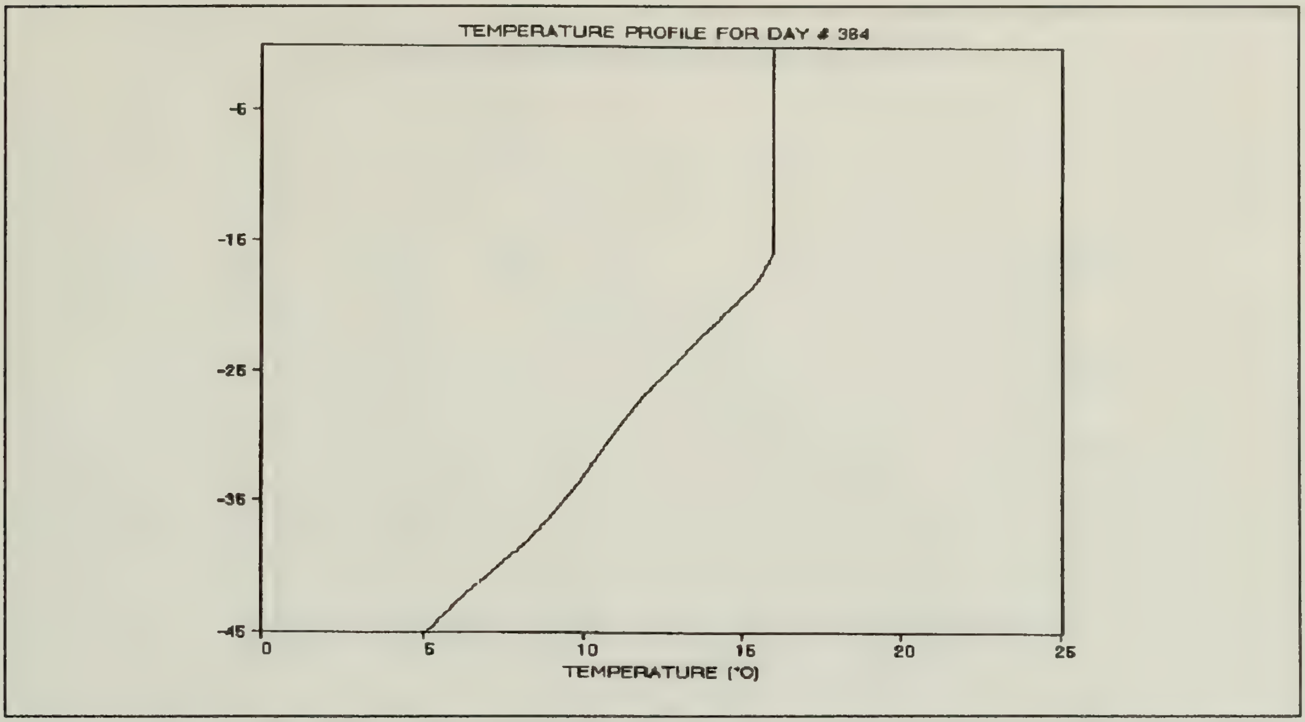


**Figure E–15. Predicted Water Temperature Profile Hungry Horse, September 30, 1969 (Above Average Flow)**

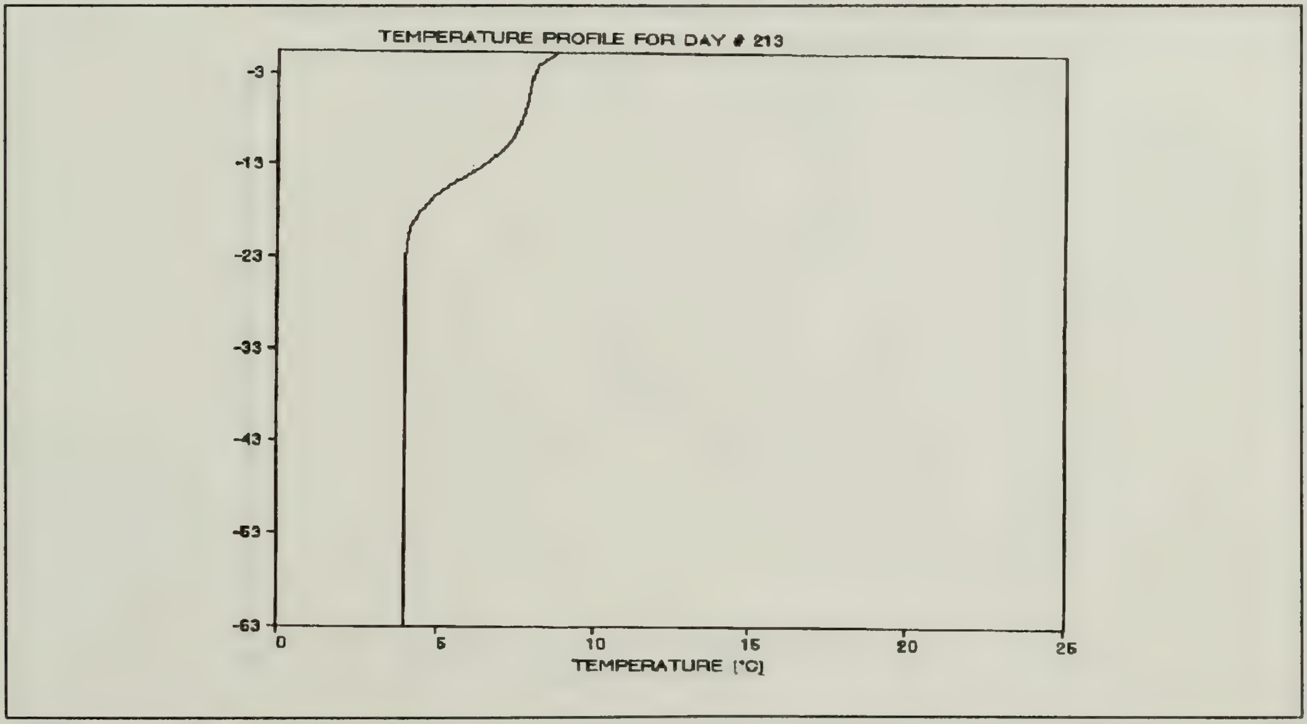


**Figure E–16. Predicted Water Temperature Profile Libby, May 1, 1981 (Below Average Flow)**

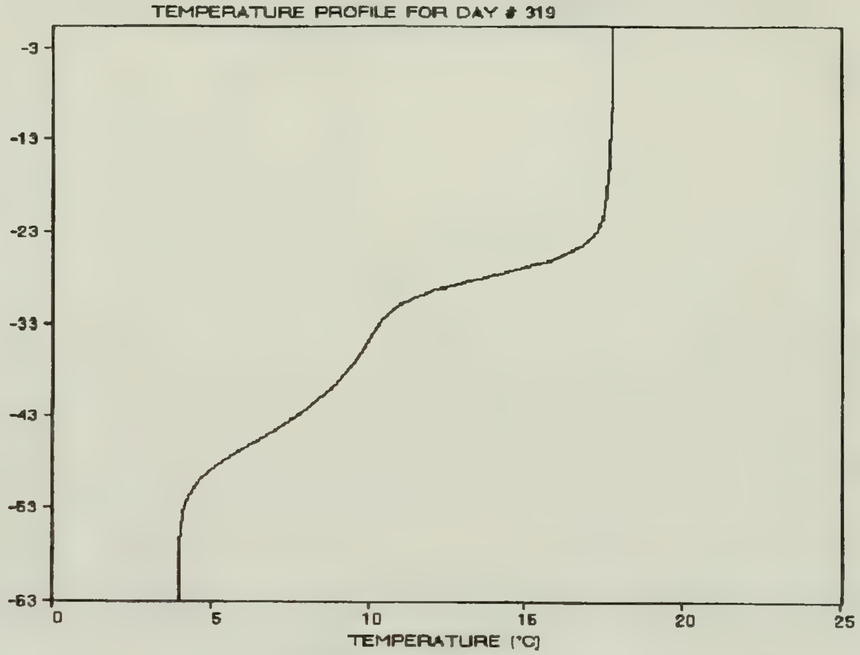


**Figure E–17.** Predicted Water Temperature Profile
Libby, August 15, 1981 (Below Average Flow)

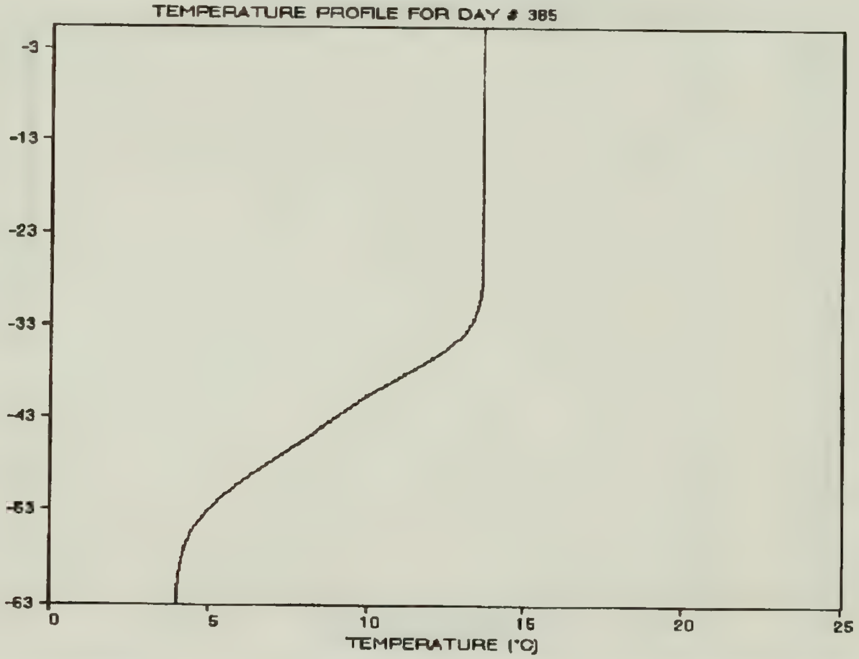


**Figure E–18.** Predicted Water Temperature Profile
Libby, September 30, 1981 (Below Average Flow)

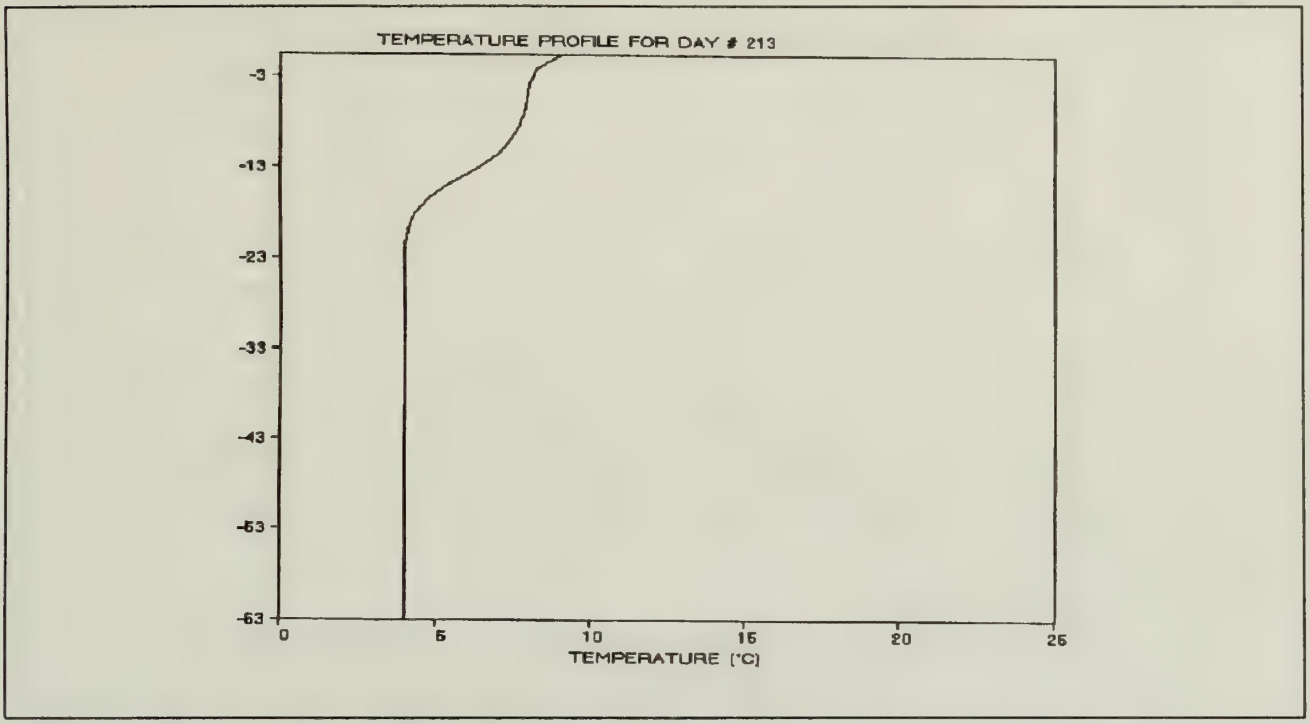


**Figure E–19. Predicted Water Temperature Profile Libby, May 1, 1957 (Average Flow)**

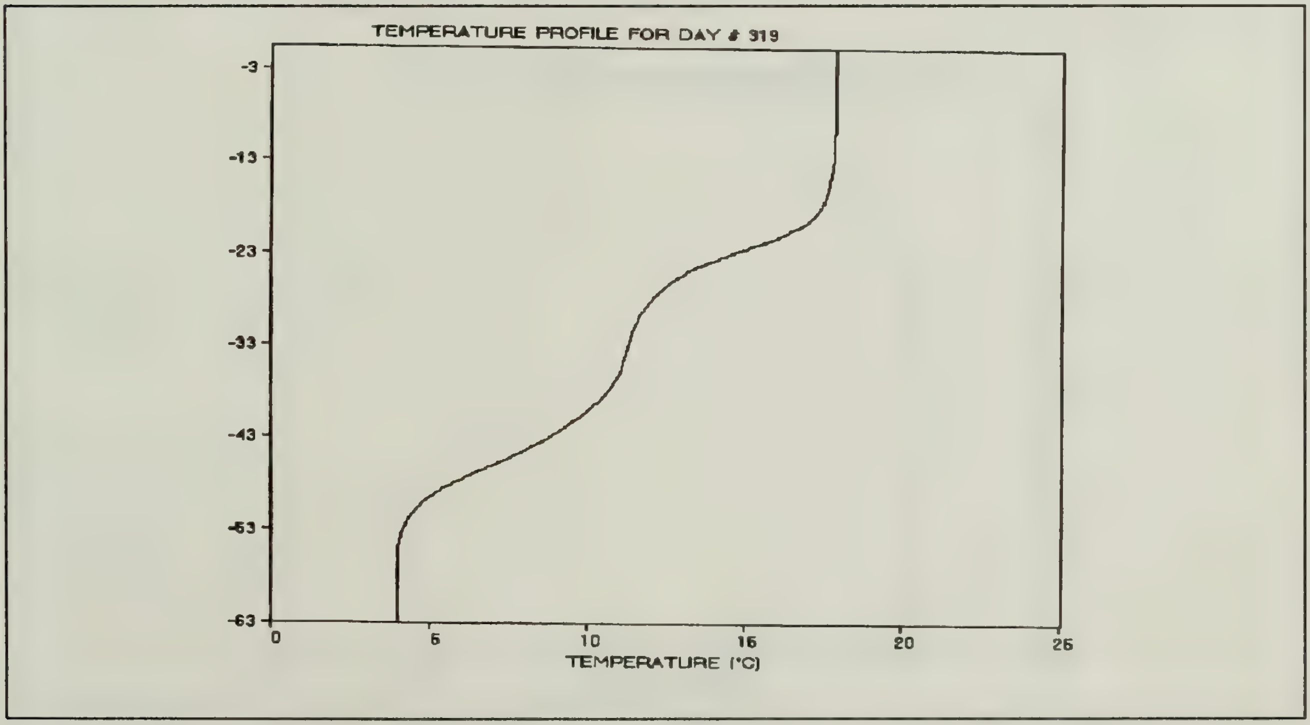


**Figure E–20. Predicted Water Temperature Profile Libby, August 15, 1983 (Average Flow)**

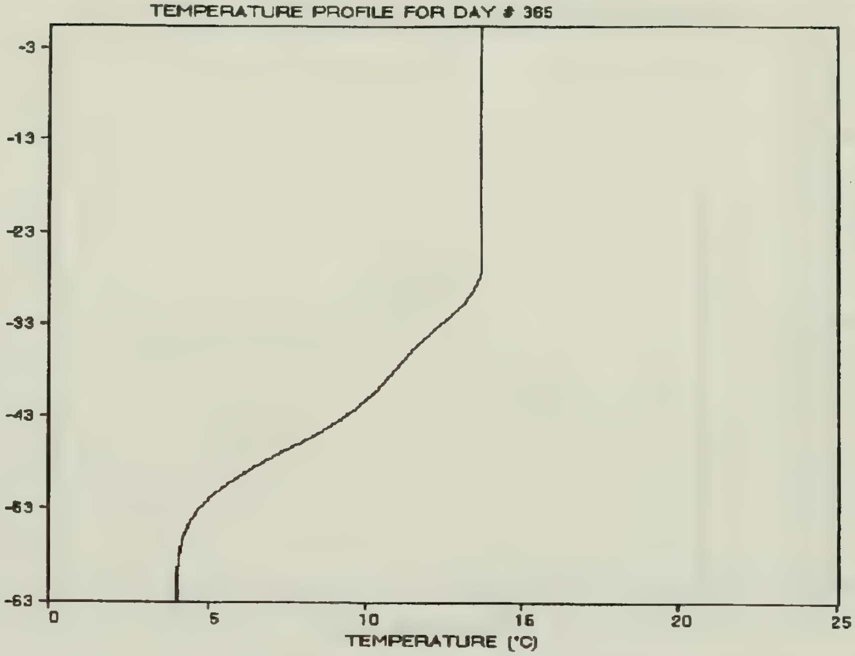


**Figure E–21.** **Predicted Water Temperature Profile Libby, September 30, 1983 (Average Flow)**

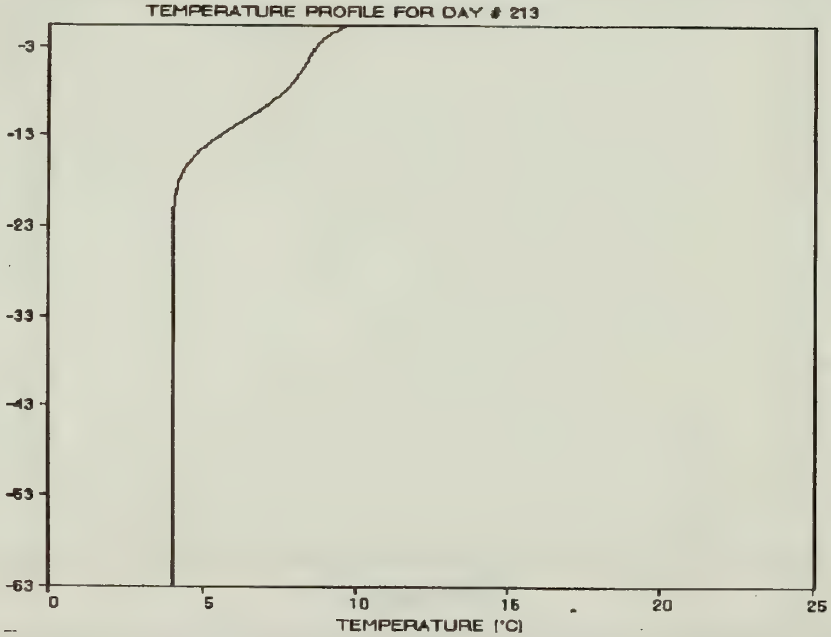


**Figure E–22.** **Predicted Water Temperature Profile Libby, May 1, 1984 (Below Average Flow)**

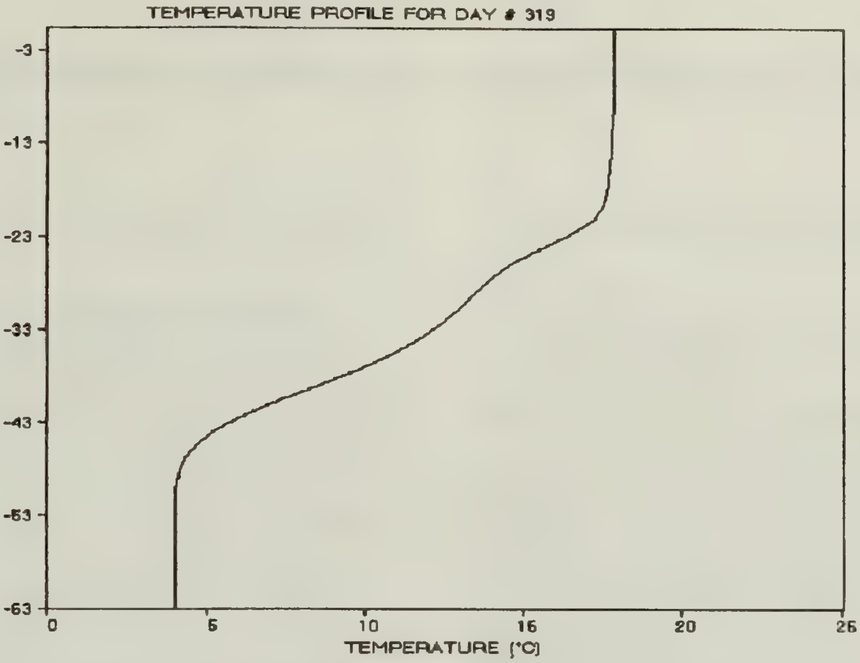


**Figure E–23. Predicted Water Temperature Profile Libby, August 15, 1984 (Below Average Flow)**

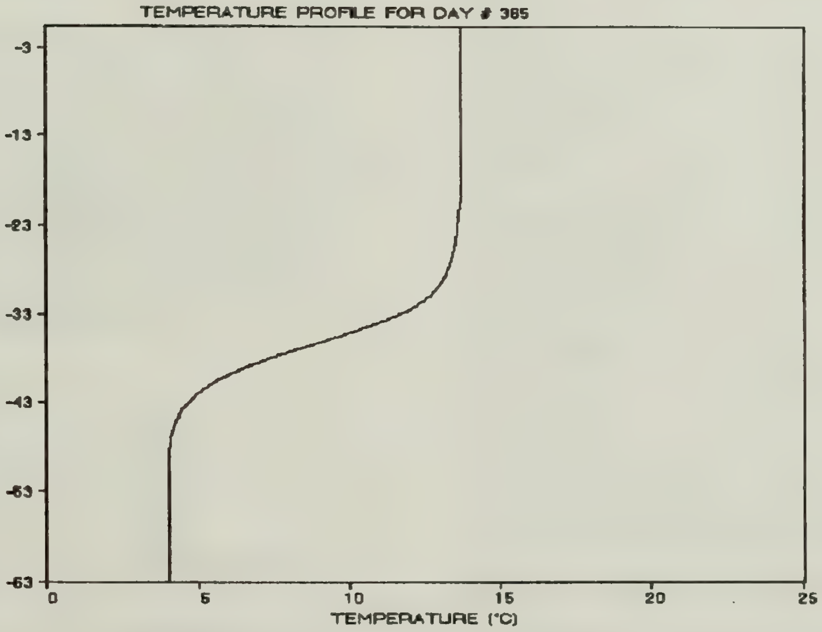


**Figure E–24. Predicted Water Temperature Profile Libby, September 30, 1983 (Below Average Flow)**

## TECHNICAL EXHIBIT F

## DESCRIPTION OF INDIVIDUAL DEEPWATER RESERVOIRS

Brownlee, Dworshak, Grand Coulee, Hungry Horse, and Libby

**BROWNLEE DAM AND RESERVOIR, IDAHO.** Brownlee Dam is located at Snake River Mile 285, 67 miles downstream from Weiser, Idaho. The dam, which is rockfill type with sloping clay core, rises 400 feet above the foundation. Full pool elevation of the reservoir is 2,077 feet, and the top of the dam is 2,090 feet. The reservoir has a capacity of 1,420,062 acre–feet, and at full pool the reservoir extends about 58 miles to approximately 9 miles below Weiser, Idaho. The concrete spillway is located on the Oregon side of the river and has a discharge capacity of 300,000 cfs at 2077 foot elevation. The powerhouse, located on the Idaho side of the river, has an installed nameplate generating capacity of 360,400 kW Provisions have been made to raise that capacity to 675,500 kW.

The Brownlee Reservoir has a dead storage below minimum power pool (El. i ,976) of 444,744 acre–feet, and a surface area at normal pool of approximately 14,621 acres. Average annual run–off at the site is 13,077,000 acre–feet, with a peak discharge of 84,500 cfs. The invert of the power intake is at elevation 1,922 m.s.l. The dam has no selective withdrawal capability. This project is owned and operated by Idaho Power Company.

Lake Elevation (ft)

| | |
|---|---|
| Maximum Pool | 2,080 |
| Full Pool | 2,077 |
| Minimum Pool | 1,976 |
| Active Capacity (1,976 to 2,077) | 975,320 acre–feet |
| Total Capacity (1,800 to 2,077) | 1,420,060 acre–feet |

Discharge (cfs)

| | |
|---|---|
| Minimum instantaneous | No limit |

Powerhouse

| | |
|---|---|
| Nameplate Capacity (kW) | 765,000 |
| Hydraulic Capacity (cfs) | 34,500 |

**DWORSHAK DAM AND RESERVOIR, IDAHO.** Dworshak Dam is a multipurpose project which controls water from the 2,440 square mile drainage area above the dam. It is located at River mile 1.9 on North Fork Clearwater River, tributary to Clearwater River. The project is operated to provide regulation for downstream flood control, power generation for use in the Northwest power system, regulation of downstream water quality, and reservoir recreation. Dworshak Dam is a straight concrete–gravity structure which has a maximum structural height of 717 feet, a hydraulic height of 632 feet, and a crest length of 3,287 feet. The crest width is 44 feet.

Lake Elevation (ft)

| | |
|---|---|
| Maximum Pool | 1,604.7 |
| Full Pool | 1,600 |
| Minimum Pool | 1,445 |
| Active Capacity (1,600 to 1,445) | 2,015,800 acre–feet |

Discharge (cfs)

| | |
|---|---|
| Minimum | 1,000 |

Powerhouse

| | |
|---|---|
| Nameplate Capacity (kW) | 400,000 |
| Hydraulic Capacity (cfs) | 10,500 |

Dworshak reservoir storage allocation is as follows:

| Elevation (ft. m.s.l.) | Storage (acre–feet) | |
|---|---|---|
| Maximum operating pool | 1600 | 3,468,000 |

| | | |
|---|---|---|
| Maximum operating pool | 1445 | 1,452,000 |
| Usable, flood control and power | 1445–1600 | 2,016,000 |
| Seasonal pool (summer) | 1600 | 3,468,000 |
| Available for seasonal flow | 1445–1600 | 2,016,000 |
| Flood pool | 1604.7 | 3,556,000 |

Rule curves for flood control (ft)

| | |
|---|---|
| September 1 | 1600.0 |
| October 1 | 1586.0 |
| November 15 | 1579.0 |
| December 15 | 1558.0 |

Minimum instantaneous project release, as established by the U.S. Fish and Wildlife Service and Idaho Department of Fish and Game, is 1,000 cfs. It is also required that flow fluctuations be kept to a minimum from 1 October through 15 November and 15 February through 1 5 April for steelhead fishing; and from 25 April to 30 June for spring Chinook salmon fishing. To protect downstream activities, the maximum allowable rate of change in water surface elevation during peaking activities is one foot per hour.

A selective withdrawal system is used to discharge water at a temperature suitable for fish production at the downstream Dworshak National Fish Hatchery. The multi–level outlet facility was provided to allow selection of the temperature of water discharging through the turbines. Initial operating objectives were to match Dworshak discharge temperatures with those of the Clearwater River just above the North Fork confluence. Temperature requirements of the downstream steelhead hatchery, however, have taken precedence over this objective. The potential exists to use releases from Dworshak for downstream water quality management.

Impoundment of the North Fork Clearwater River has resulted in a cold, nutrient–poor lake with low biological productivity and high aesthetic water quality. In the initial post–impoundment years, decomposition of organics resulted in hypolimnetic oxygen depletion and hydrogen sulfide production. This condition, however, has not been observed in recent years and is not expected to recur. The impoundment has moderated water temperatures in the system, and the temperature regime of the North Fork and main stem Clearwater Rivers has moved toward the mean, with warmer winter flows and cooler summer flows.

Heating and cooling requirements of water used for fish production at the downstream steelhead hatchery are dictated by Dworshak outflow temperatures. In recent years, the selective withdrawal system has been used to provide the hatchery with suitable temperatures. With the altered temperature regime of the lower Clearwater River, cold–water game fish habitat has been improved.

Before Construction of Dworshak Dam, the lower Clearwater River supported a substantial smallmouth bass fishery. The altered temperature regime has suppressed smallmouth bass reproduction and the fishery is now considered marginal. During periods of spill from the reservoir, gas supersaturation has occurred at levels which violate State of Idaho water quality standards. Periods of spill, however, are infrequent and no adverse effects on the ecosystem have been observed.

Because of the high recreational use of the reservoir, it is an operational objective to fill to elevation 1600 each year. Special consideration is given to avoid evacuating the reservoir during winter or spring months below the level that will assure at least a 95 percent chance of refilling to elevation 1570 by 1 July.

Addition of a 4th unit to the Dworshak project has been proposed. Operation of an additional unit would increase peak daily discharge during peaking operations from 10,000–11,000 cfs to 16,000–17,000 cfs. Based on preliminary studies, it appears that four units could be operated within the one–foot–per–hour–maximum rate of change in water surface elevation limitation. The total daily river fluctuation in the summer months would increase approximately one foot.

**GRAND COULEE DAM AND RESERVOIR, WASHINGTON.** The Grand Coulee Dam, essentially completed in 1941, is one of the largest concrete structures in the world (11,975,500 cubic yards of concrete). Straddling the Columbia River the dam towers 550 feet from bedrock to crest and tapers from width of more than 500 feet at its base to 30 feet at its top. Its reservoir, Franklin D. Roosevelt Lake, extends 151 miles northeast to the Canadian border, and up the Spokane River, a tributary of the Columbia, to within 37 miles of Spokane. The reservoir has 600 miles of shoreline, a 82,000 acre surface area, and a total capacity is 9,562,000 acre–feet (of which 5,185,400 acre–feet are active storage).

The project is operated by the Bureau of Reclamation for power generation, flood control, irrigation, river regulation, navigation, and downstream power production. Total generating capacity for the Grand Coulee hydropower installation is 6,480,000 kW. There are no selective withdrawal capability.

Lake Elevation (ft)

| | |
|---|---|
| Normal Full Pool | 1,290 |
| Normal Minimum Pool | 1,208 |
| Active Capacity (1,290 to 1,208) 5,185,500 acre–feet | |

Powerhouse

| | |
|---|---|
| Nameplate Capacity (kW) | 6,494,000 |
| Hydraulic Capacity (cfs) | 280,000 |

Rule curve for flood control: varies by year as established by the Corps of Engineers in advance of flood season based on predicted runoff.

**HUNGRY HORSE DAM AND RESERVOIR, MONTANA.** Hungry Horse Dam is located at River Mile 5.2 on the South Fork of the Flathead River, Montana, in a deep and narrow canyon. At the time of its completion in 1953, Hungry Horse was the third largest and second highest concrete dam in the world. This project is owned and operated by the Bureau of Reclamation for power, flood control, irrigation, navigation, and other uses. Downstream power benefits are of major importance; more than five times as much power can be produced from water releases downstream than is produced at Hungry Horse Powerplant.

The 564–foot–high dam is a variable–thickness concrete arch structure with a crest length of 2,115 feet. The dam and appurtenant works contain 3,086,200 cubic yards of concrete. The spillway is the highest morning–glory structure in the world. Water cascading over the spillway rim drops a maximum distance of 490 feet.

Hungry Horse Reservoir is located high in the Rocky Mountains, less than 30 miles from the Continental Divide, and is surrounded by 25 mountain peaks. The reservoir is about 34 miles long and a total capacity of 3,468,000 acre–feet.

Lake Elevation (ft)

| | |
|---|---|
| Maximum Regulated pool (surcharge) | 3,565 |
| Normal Full Pool | 3,560 |
| Minimum Pool | 3,336 |
| Active Capacity (3,336 to 3,560) 3,161,000 acre–feet | |

Discharge (cfs)

| | |
|---|---|
| Minimum | 400 |
| Maximum | 500–3,000 |

Powerhouse

| | |
|---|---|
| Nameplate Capacity (kW) | 285,000 |
| Hydraulic Capacity (cfs) | 8,900 |

Maximum release during periods of flood control operations to reduce damages on the main Flathead River is 500 cfs. During flood control operations to reduce damages on the lower Columbia River, releases will be limited to 3,000 cfs or less.

**LIBBY DAM AND RESERVOIR, MONTANA.** Libby Dam project is located in northwestern Montana in Lincoln County, on the Kootenai River at River Mile 221.9, about 48 miles west–northwest of Kalispell, Montana. This is owned and operated by the Corps of Engineers Seattle District for flood control and hydropower generation both at the project site and downstream.

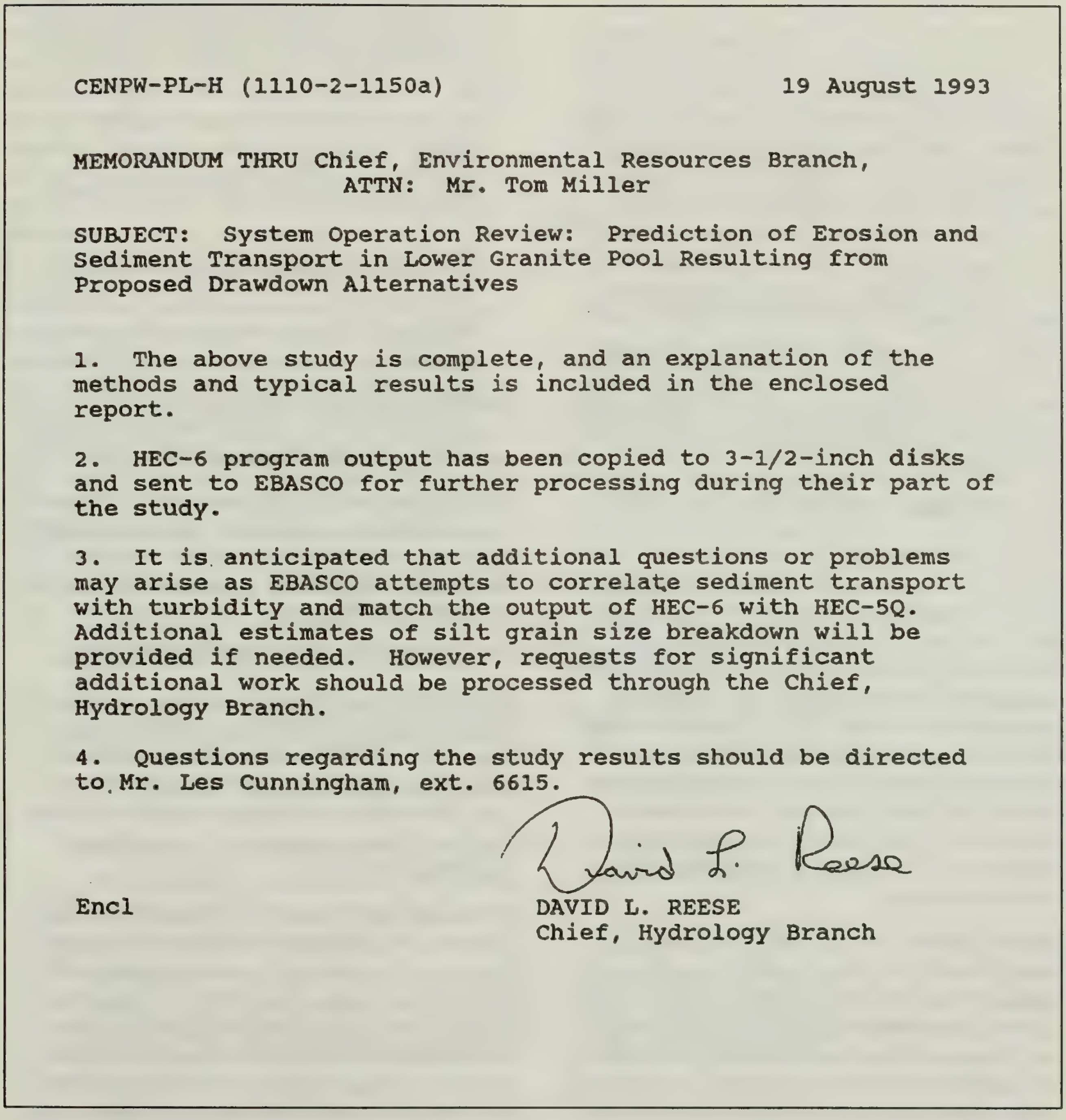
Libby Dam is a concrete gravity structure with a total length of 2,887 feet and a maximum height of 432 feet from bedrock to the road–way deck on the top of the dam. The Libby fore bay reservoir, Lake Koocanusa, is approximately 90 miles long (48 miles in the United States and 42 miles in Canada). Normal full pool and minimum regulated reservoir elevations are 2,459 and 2,287 feet respectively. The gross storage and usable storage are 5,869,392 and 4,979,468 acre–feet respectively. Reservoir area at normal full pool is 46,456 acres.

A multiple–bulkhead intake system permits selective withdrawal of water from a water column of selected depth above elevation 2,222 feet for discharge through the powerhouse. The powerhouse has a name plate generation capacity of 525,000 kW under 337 feet of head, and a hydraulic capacity of 24,100 cfs.

| | | |
|---|---|---|
| Lake Elevation (ft) | | |
| Maximum Pool | 2,459 | |
| Full Pool | 2,459 | |
| Minimum Pool | 2,287 | |
| Active capacity (2,459 to 2,287) acre–feet | | 4,979,500 |
| Discharge (cfs) | | |
| Minimum instantaneous | 2,000 | |
| Minimum daily flow | 3,000 | |
| Powerhouse | | |
| Nameplate Capacity (kW) | 525,000 | |
| Hydraulic Capacity (cfs) | 24,100 | |
| Rule curves for flood control (ft) | | |
| November 1 | 2459.0 | |
| December 1 | 2449.0 | |
| January 1 | 2410.0 | |

## TECHNICAL EXHIBIT G

## PREDICTION OF EROSION AND SEDIMENT TRANSPORT



CENPW-PL-H (1110-2-1150a) 19 August 1993

MEMORANDUM THRU Chief, Environmental Resources Branch,
ATTN: Mr. Tom Miller

SUBJECT: System Operation Review: Prediction of Erosion and Sediment Transport in Lower Granite Pool Resulting from Proposed Drawdown Alternatives

1. The above study is complete, and an explanation of the methods and typical results is included in the enclosed report.

2. HEC-6 program output has been copied to 3-1/2-inch disks and sent to EBASCO for further processing during their part of the study.

3. It is anticipated that additional questions or problems may arise as EBASCO attempts to correlate sediment transport with turbidity and match the output of HEC-6 with HEC-5Q. Additional estimates of silt grain size breakdown will be provided if needed. However, requests for significant additional work should be processed through the Chief, Hydrology Branch.

4. Questions regarding the study results should be directed to Mr. Les Cunningham, ext. 6615.

David L. Reese

Encl

DAVID L. REESE
Chief, Hydrology Branch

## SYSTEM OPERATION REVIEW SEDIMENT STUDY

### Prediction of Erosion and Sediment Transport in Lower Granite Pool Resulting from Proposed Drawdown Alternatives

## G–1 INTRODUCTION

In the process of evaluating the impact of proposed drawdown alternatives for Lower Granite and other reservoirs, the increase in turbidity during a drawdown was of interest due to its possible effect on fish and other aquatic life in the reservoir. Hydrology originally proposed that the turbidity increase be roughly estimated based on observations made during the drawdown and gross estimates of potential erosion. However, others felt a computed solution based on the Hydrologic Engineering Center's HEC–6 sediment transport model would be more appropriate. The model results for Lower Granite Pool were to be used by EBASCO to calibrate an HEC–5Q model which, in turn, would model turbidity, and other water–quality parameters for a much longer reach of the Snake River.

## G–2 PURPOSE AND SCOPE

The purpose of this report is to describe the methods used to calculate sediment transport, the limitations of the method, and to present enough examples of the results to give the reader a general understanding of how sediment is transported during varying flow conditions and drawdown levels. No attempt is made to cover all of the various combinations of alternatives actually evaluated during this study. The program output for each alternative was provided to EBASCO and it is assumed that the results of their study will provide a more complete coverage of the issues that are significant to future drawdown decisions.

Hydrology studies were limited to the modeling of Lower Granite Pool using the HEC–6 computer sediment transport model. Hydrology prepared input for the upstream sediment supply from the Snake and Clearwater Rivers and for below–water–surface portions of the pool. An estimate was also made of the volume of material subject to potential erosion in the remaining three downstream reservoirs on the Snake River. No attempt was made to convert sediment concentrations to turbidity.

EBASCO estimated wind–wave erosion, and erosion from exposed mud flats and delta areas of the pool. This "above–water" sediment data was input into a selection of the HEC–6 model runs as "local inflow" to see how the model transported the material. Four basic drawdown alternatives were considered:

> Alternative 2: Operation at minimum pool (MOP).
>
> Alternative 6: Operation with the pool lowered 33–ft.
>
> Alternative 7: Operation with the pool lowered 52–ft.
>
> Alternative 5: Operation with pool lowered as far as possible.

Alternatives 6, 7, and 5 were evaluated for a 2–month, and a 4–1/2–month drawdown period; and for high, medium, and average flow years.

The program provided daily output for sediment transport rates by grain size for each cross section, the change in bed elevation, and trap efficiency. It also provided yearly totals of sediment transport and deposition by cross section.

## G–3 CALIBRATION OF THE HEC–6 MODEL

The original Lower Granite model was calibrated for reservoir operation within the normal operating range (733 – 738 ft), and operated almost exclusively as an aggrading model. The model extended from RM 7.85 on the Clearwater and RM 148.83 on the Snake River, downstream to Lower Granite Dam (RM 107.43).

It was calibrated to match observed sediment accumulation and distribution as calculated from sediment range resurveys of the reservoir starting with the pool raise in the spring of 1975. A map of the location of the present ranges is found on plate 1. The original model contained a gravel and cobble bed for a starting channel bed gradation, incoming sediment accumulated over this bed. Sediment load curves for suspended and bed load entering the upper boundary of the model were based on U.S. Geological Survey sediment transport measurements covering the period 1972 through 1978 at the USGS gages "Snake River near Anatone," and "Clearwater River at Spalding."[1] Although a different gradation was estimated for each discharge range, there was actually a rather poor correlation between flow and percent of fines. Plate 2 illustrates the variation that can occur on the Clearwater River during the year. The percentage of fines is influenced more by source and availability than by channel erosion or transport capacity. Heavy rains often wash large quantities of silt into the river from cultivated fields. The river is often a muddy brown after a heavy rain even during low flow.

In order to use the model for erosion studies, the bed gradation for the model was completely recoded. Initial bed gradations were based on laboratory gradation tests of sediment samples taken from the reservoir bed averaged over approximately 5–mile reaches of the pool. Observed rates of sediment deposition appeared to be reproduced much better in the model when all silt sized material between 0.004 and 0.0625 mm were transported as coarse silt (0.031 – 0.0625 mm). In order to be consistent within the model all silt sizes for both the bed and the upstream supply were expressed as coarse silt.

The HEC–6 model is one–dimensional: Sediment data, sediment transport, and hydraulic parameters vary only in the direction of flow. They do not vary laterally or with depth. In some areas, particularly where the gradation varied laterally, some grainsize adjustments were necessary in order to calibrate the model to erosion and deposition observed during the 1992 drawdown test. At some sections in the vicinity of the confluence it was necessary to set limits to the width of the low flow channel in order to duplicate the 1992 event. Plates 3 and 4 compare the observed and modeled erosion during the 1992 event. Before–and–after–drawdown surveys only extended down to River–Mile (RM) 130.

## G–4 DRAWDOWN MODELING USING HEC–6

In order to define varying conditions for the various drawdown alternatives, A total of thirty–seven different sets of input data were developed for the HEC–6 model. Twenty–five of these sets are listed below. Note that only the last four sets (the names not ending with z) included erosion input from above–pool mud flats and deltas.

| | |
|---|---|
| 2AHIZ.ZIP | 3–1/2 MONTH DD TO MOP, NO LOCAL INFLOW, HIGH Q |
| 2AMEDZ.ZIP | 3–1/2 MONTH DD TO MOP, NO LOCAL INFLOW, MEDIUM Q |
| 2ALOWZ.ZIP | 3–1/2 MONTH DD TO MOP, NO LOCAL INFLOW, LOW Q |
| 5BHIZ.ZIP | 4–1/2 MONTH, NORMAL D, NO LOCAL INFLOW, HIGH Q |
| 5BMEDZ.ZIP | 4–1/2 MONTH, NORMAL D, NO LOCAL INFLOW, MEDIUM Q |
| 5BLOWZ.ZIP | 4–1/2 MONTH, NORMAL D, NO LOCAL INFLOW, LOW Q |
| 6BHIZ.ZIP | 4–1/2 MONTH, 33–FT DD, NO LOCAL INFLOW, HIGH Q |
| 6BMEDZ.ZIP | 4–1/2 MONTH, 33–FT DD, NO LOCAL INFLOW, MEDIUM Q |
| 6BLOWZ.ZIP | 4–1/2 MONTH, 33–FT DD, NO LOCAL INFLOW, LOW Q |
| 7BHIZ.ZIP | 4–1/2 MONTH, 52–FT DD, NO LOCAL INFLOW, HIGH Q |
| 7BMEDZ.ZIP | 4–1/2 MONTH, 52–FT DD, NO LOCAL INFLOW, MEDIUM Q |
| 7BLOWZ.ZIP | 4–1/2 MONTH, 52–FT DD, NO LOCAL INFLOW, LOW Q |
| 5AHIZ.ZIP | 2–MONTH, NORMAL D, NO LOCAL INFLOW, HIGH Q |

| | |
|---|---|
| 5AMEDZ.ZIP | 2–MONTH, NORMAL D, NO LOCAL INFLOW, MEDIUM Q |
| 5ALOWZ.ZIP | 2–MONTH, NORMAL D, NO LOCAL INFLOW, LOW Q |
| 6AHIZ.ZIP | 2–MONTH, 33–FT DD, NO LOCAL INFLOW, HIGH Q |
| 6AMEDZ.ZIP | 2–MONTH, 33–FT DD, NO LOCAL INFLOW, MEDIUM Q |
| 6ALOWZ.ZIP | 2–MONTH, 33–FT DD, NO LOCAL INFLOW, LOW Q |
| 7AHIZ.ZIP | 2–MONTH, 52–FT DD, NO LOCAL INFLOW, HIGH Q |
| 7AMEDZ.ZIP | 2–MONTH, 52–FT DD, NO LOCAL INFLOW, MEDIUM Q |
| 7ALOWZ.ZIP | 2–MONTH, 52–FT DD, NO LOCAL INFLOW, LOW Q |
| 5BHI.ZIP | 4–112 MONTH, NORMAL D, LOCAL INFLOW, HIGH Q |
| 6BHI.ZIP | 4–1/2 MONTH, 33–FT DD, LOCAL INFLOW, HIGH Q |
| 6BLOW.ZIP | 4–1/2 MONTH, 33–FT DD, LOCAL INFLOW, LOW Q |
| 7BHI.ZIP | 4–1/2 MONTH, 52–FT DD, LOCAL INFLOW, HIGH Q |

After completing the above, twelve more "unshielded runs" were made covering alternatives 5 and 7 with only fine sand, silt and clay in transport. This scenario will be discussed in greater detail in the Discussion of Model Results.

### G–4.1 Development of Hydrographs

One of the first steps in setting up the data was to develop the flow hydrographs. Study managers at the Corps Division office decided to use the water years 1974, 1959, and 1973 to represent conditions during a high, medium, and low–flow year. A water–year starts in 1 October of one calendar year and extends to September 30 of the following year. For instance water–year 1974 extends from calendar date 1 October 1973 to 30 September 1974. All of the above models were set up to run for five year periods. The extreme years were placed at the beginning and end of the five–year series with three average (1959) years in between.

Hydrographs for input into program HEC–6 were calculated by the University of Washington and obtained by the Walla Walla District from the Corps of Engineer's Reservoir Control Center (RCC). The supplied hydrographs were based on proposed regulation of monthly average flows for calendar years 1958, 1959, 1972, 1973, and 1974, with 15 day averages calculated for the months of April and August of each year. A random modulation was superimposed on the monthly average values to simulate daily fluctuations. Plate 5 represents a typical hydrograph plotted from data received from RCC.

These above data were reprocessed in the Walla Walla District by recalculating the monthly and by–weekly average values and then expressing the resultant data as daily flows. The discontinuities in flow at the end of each month were smoothed by calculating 5–day running averages of the daily data. For the 1974 water year a short peak–flow was added to simulate worst–case erosion conditions during the high flow year. Plates 6–11 indicate the calculated hydrographs compared to observed flows during those years. For input into HEC–6 the hydrographs were strung together in 5–year sequences as follows:

| | |
|---|---|
| HIGH Q: | 1974–1959–1959–1959–1974 |
| MEDIUM Q: | 1959–1959–1959–1959–1959 |
| LOW Q: | 1973–1959–1959–1959–1973 |

The model was set up to calculate sediment discharges for one–day time steps during the drawdown period, and for 15–day time steps during the remainder of the year. At the end of each year the total sediment passing each sediment range was output along with a summary of erosion or deposition volumes at each location. The output was compressed and placed on 3−1/2 inch floppy disks, copies were sent to EBASCO.

### G–4.2 Development of Forebay Elevations for the drawdown.

The drawdown proposals called for a pool drop of 2−ft per day until the pool reached the target level by April 15 of each year. This was followed by an either 2 or 4−1/2 month period when the pool was allowed to fluctuate within a range of 5 feet below the target elevation. Then, starting at the farthest downstream reservoir, the pool would be raised as fast as possible while maintaining a minimum 11,000 cfs flow through all projects. For input data in HEC−6, it was assumed that the pool would remain at the bottom of the 5−ft level during the scheduled drawdown period. The actual length of the drawdown and the rate of refill of Lower Granite Pool were calculated from the flow rate and the time it would take to progressively refill each pool starting at Ice Harbor Pool and working upstream. During a low−flow year the refill time could extend into the next water year. The pool elevation sequences used in the model are shown on Plates 12 − 14. Note that for the case of drawdown to normal depth (no dam in place at the Lower Granite dam site), the minimum pool level varies with the flow. If the dam is not completely removed the minimum pool levels could be somewhat higher than indicated and could result in the trapping of some additional sediment upstream.

### G–4.3 Potential Erosion Limitation

Prior to completion of Lower Granite Dam the bed of the Snake River consisted largely of gravel and cobbles ranging from 3 to 12 inches in diameter. It was assumed that only the sediment deposited above this original bed layer would be subject to erosion during a drawdown. The starting bed geometry for the model was based on the latest surveys taken before drawdown (1989 or 1992 surveys). The allowable erosion depth was limited to the depth required to remove the observed volume of sediment between the original channel bed and the starting bed for the model.

Three local inflow points were established to handled erosion products entering the river from lands above the water surface during the drawdown. These were located just downstream of PM 120.46, 130.66, 139.22. The location was chosen primarily to provide uniform separation of the inflow points along the river while giving consideration to the location of contributing land areas. Sediment inflow was provided by EBASCO.

## G–5 DISCUSSION OF RESULTS

### G–5.1 Comparison of Drawdown Alternatives

As previously stated, no attempt will be made to cover all of the alternatives or the sediment transport rates contained in the program output. Plates 15 though 27 provide an illustration of typical results. Plates 15 and 16 indicate relative differences between annual transport and deposition of silt, sand, and clay for the first year for each of the drawdown levels for the case of a two−month drawdown. In this set of data all sand sizes are transported resulting in significant shielding of downstream silt and clay. Note that the total erosion and transport of sediments of all sizes increases with the magnitude of the drawdown. All alternatives except 5 trap all of the sand within the reservoir. Option 2 traps nearly all sizes except clay.

### G–5.2 Shielding of Silt and Clay Deposits

In all of the computer runs, particularly those with the high flow sequences, considerable interference with the erosion and entrainment of clay and silt in the lower half of the reservoir was noted. See Plate 22. Even though the shear stress threshold for erosion was considerably exceeded, no silt or clay was being eroded from some areas of the lower reservoir. A careful evaluation of the output indicated that a considerable amount of sand was in transport or had been deposited over the silt and clay during the drawdown phase. The HEC−6 program algorithm prevents any erosion of silt and clay below a thin surface layer called the “cover layer” as long as any depth of sand remains in this layer. This phenomenon has been observed and is described in paragraph 2.3.3.1, page 27 −28, of the June 1991 edition of the HEC−6 Users Manual. In models with high inflowing sediment, (and with all grain sizes included), very little silt and clay is eroded by the model downstream of RM 135 even during total drawdown to normal depth. It is probable that the inflowing sediment is close to its transport capacity at the upper boundary of the model and sand sized materials deposited while a partial pool remains are not completely removed during the free−flowing phase of the drawdown.

While there is little question that the above "armoring" or −perhaps more correctly− "shielding" does occur, the program does not account for head cutting, the formation of ripples and dunes or unequal lateral distribution of sediment which could expose the underlying silts and clay to erosion. The extent to which headcutting and unequal distribution of sand deposits would accelerate the erosion of fines during a drawdown is not known. It would seem possible for relatively high erosion rates to occur for short periods of time during episodes of head cutting through delta deposits. The actual maximum, short−term erosion rate is probably considerably higher than the "shielded" case but somewhat lower than would occur if no sand shielding were occurring.

A surface armor layer of larger particles was observed on the Alpowa delta during the 1992 drawdown. Vertical erosion of this delta progressed as a series of head cuts, starting at the lower end of the channel and working upstream. Considerable material was added by bank sloughing combined with lateral migration of the channel. Periods of very low turbidity were followed by very high turbidity as material from a bank failure was eroded and carried downstream.

In order to obtain an upper bound to the fine sediment erosion and transport all sand above very fine sand 0.125 mm removed from the bed and the upstream supply. The erosion rate on Alpowa delta was used as a guide in setting the silt erosion rate at the mass−erosion break point. As expected the silt progressively eroded down to the original cobble layer as the very fine sands. A total of 12 computer runs were made covering reservoir level dropped with only minimal interference from the all options for the 52−ft drawdown and the drawdown to normal depth. A comparison of the sand shielded vs unshielded model results for the 2−month, 52−ft drawdown is shown on Plates 17 and 18. Note the considerably higher transport in the confluence area for the shielded case due to the supply of coarse sand. The difference in supply at the upstream end of the model represents the sands above 0.125 mm. The silt and clay is the same at the upstream end where it is controlled by the inflowing supply, but is much lower in the shielded area downstream of the confluence since the silt and clay sediment is not being entrained into the flow. Below RM 120 there is a noticeable reduction in transport for both the shielded and unshielded cases, since silt is being deposited in the remaining pool.

Plates 19 and 20 compare the shielded and unshielded case for the drawdown to normal depth during the first year of and average−flow sequence (1959), while Plates 21 and 22 indicated the comparison during the first high−flow year (1974). The results are similar to alternative 7 except there is no deposition for the unshielded case since sand, silt, and clay eventually erode and are transported out the lower end of the model.

The unshielded case represents the most severe case with respect to the transport of silt and clay. The transport of sand is somewhat higher for the shielded case but this may be masked by the very high local inflow from mud flats and wind−wave erosion in the model calculations.

### G–5.3 Changes in transport with time and flow

Plates 23 and 24 indicates the change in transport for the shielded case for the full drawdown and high−discharge for each year of the five−year sequence. Sediment transport is greatly reduced and much closer to the inflowing supply after the first year. In the unshielded case (Plate 25), the difference between inflowing sediment and outflow is almost insignificant after the first year. Plate 26 illustrates the relative difference in transport during the first year for a high (1974), medium (1959), and low flow (1973) year for the unshielded case.

### G–5.4 The effect of local inflow

Plate 27 indicates the total transport when the local inflow from deltas and mud flats is included. Note that the first year contribution from above–water areas is about twice the contribution from below thee water surface even for the unshielded case. It appears that local inflow will likely be the controlling factor and may mask minor variations in the channel for most of the modeling effort.

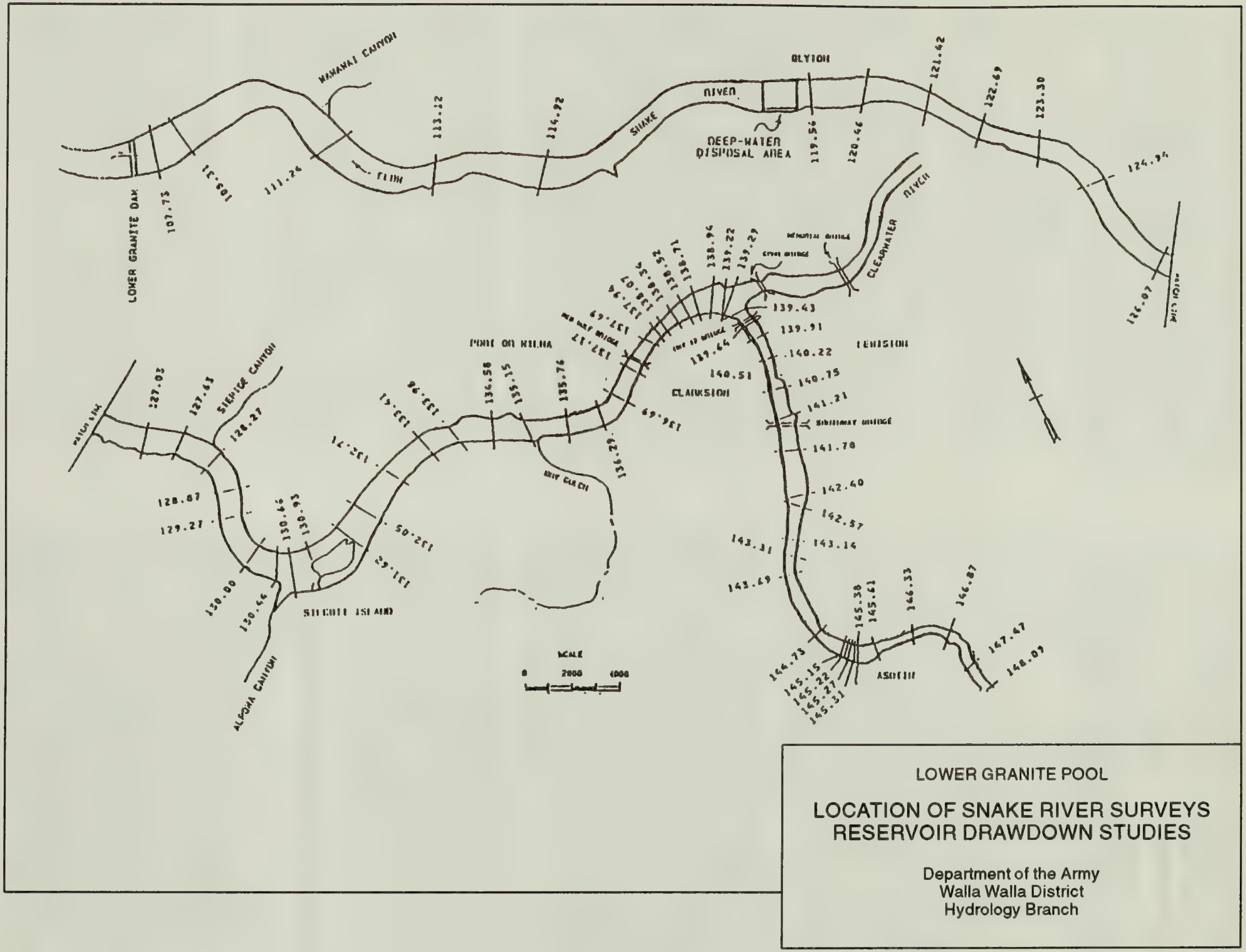


Figure G–1. Plate 01: Location of Snake River Surveys Reservoir Drawdown Studies

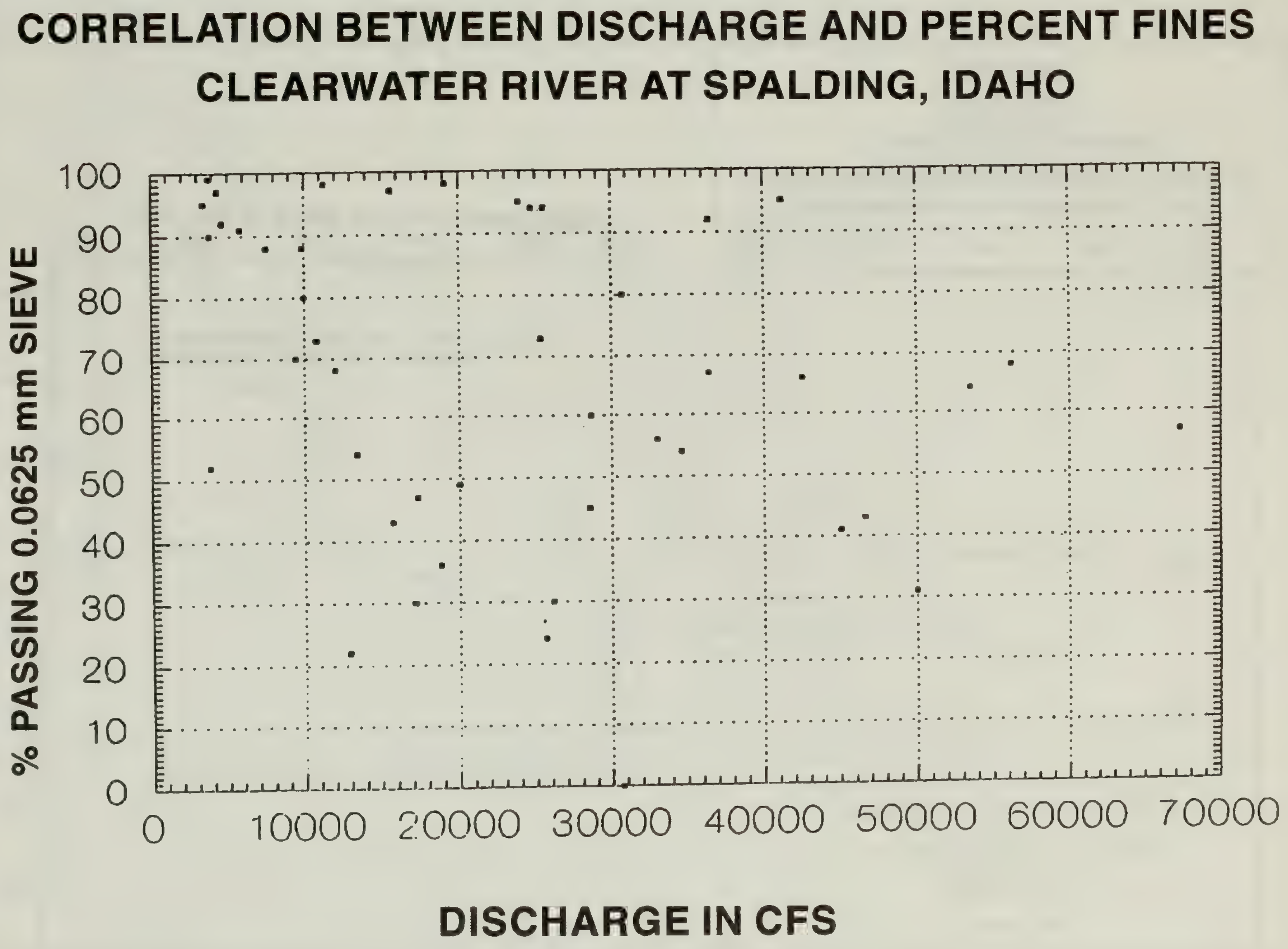


Figure G–2. Plate 02: Correlation Between Discharge and Percent Fines Clearwater River at Spalding, Idaho

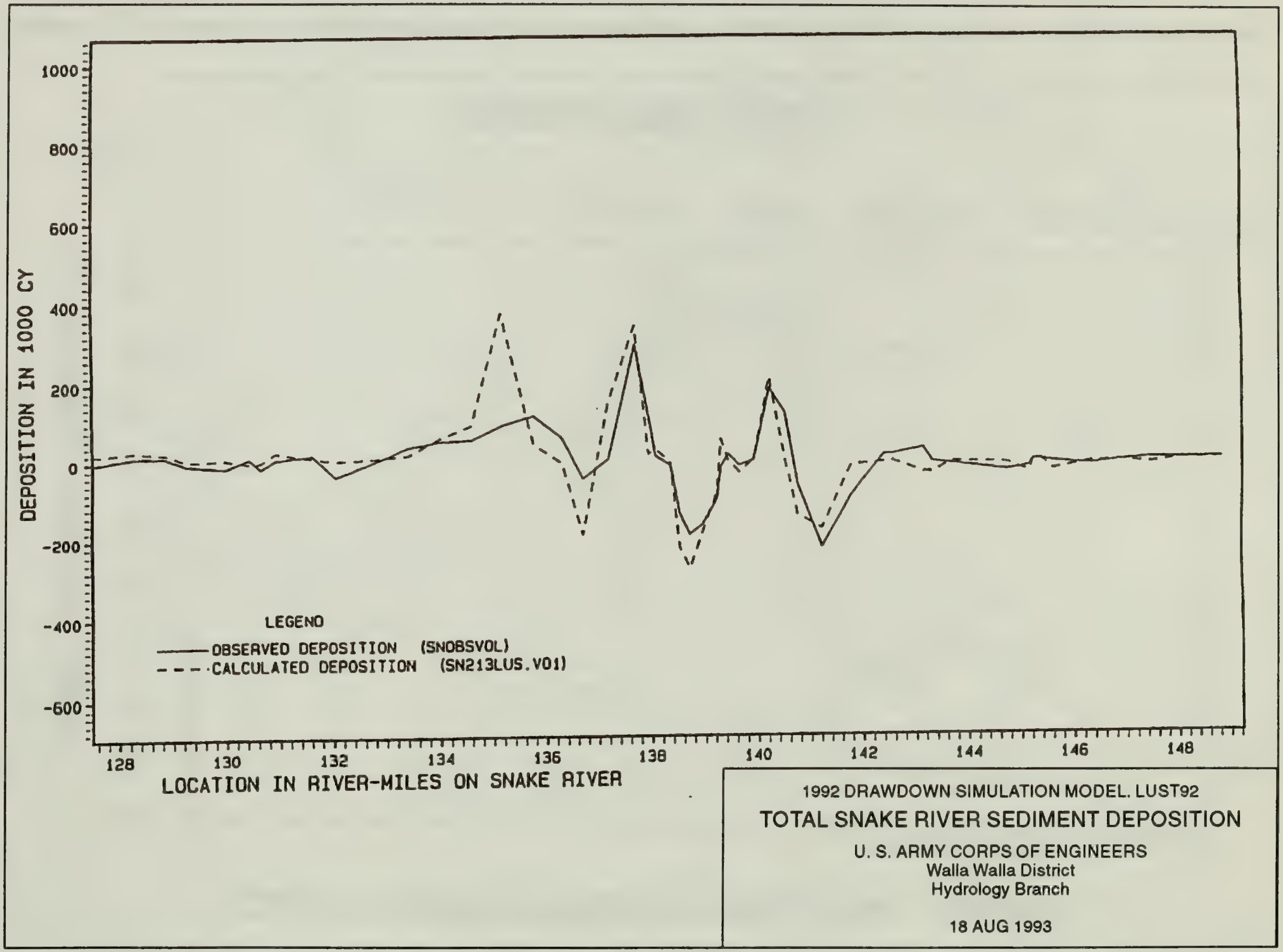


Figure G–3. Plate 03: Total Snake River Sediment Deposition (Rm 128 – 148)

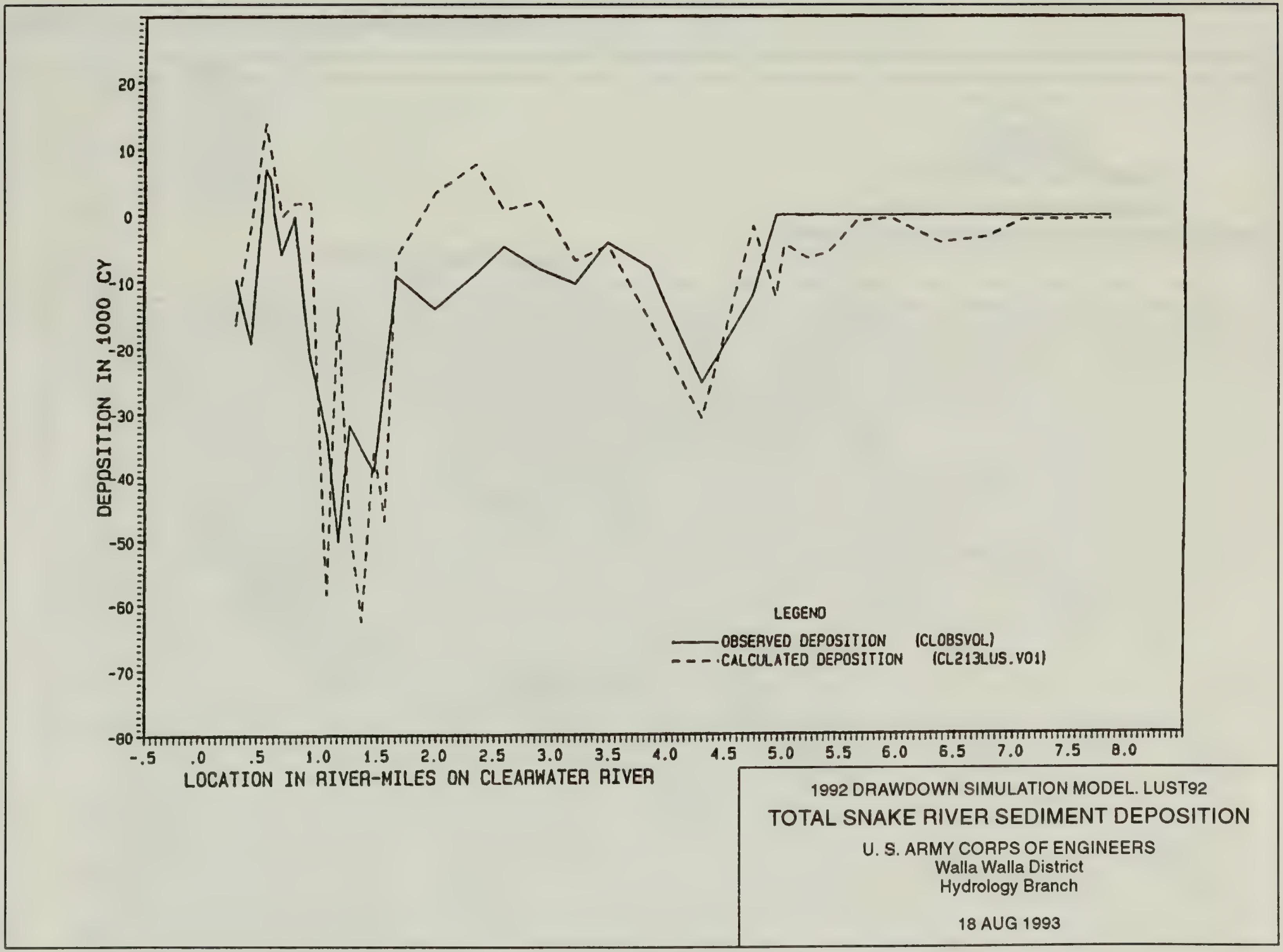


Figure G–4. Plate 04: Total Snake River Sediment Deposition (Rm –.5 to 8.0)

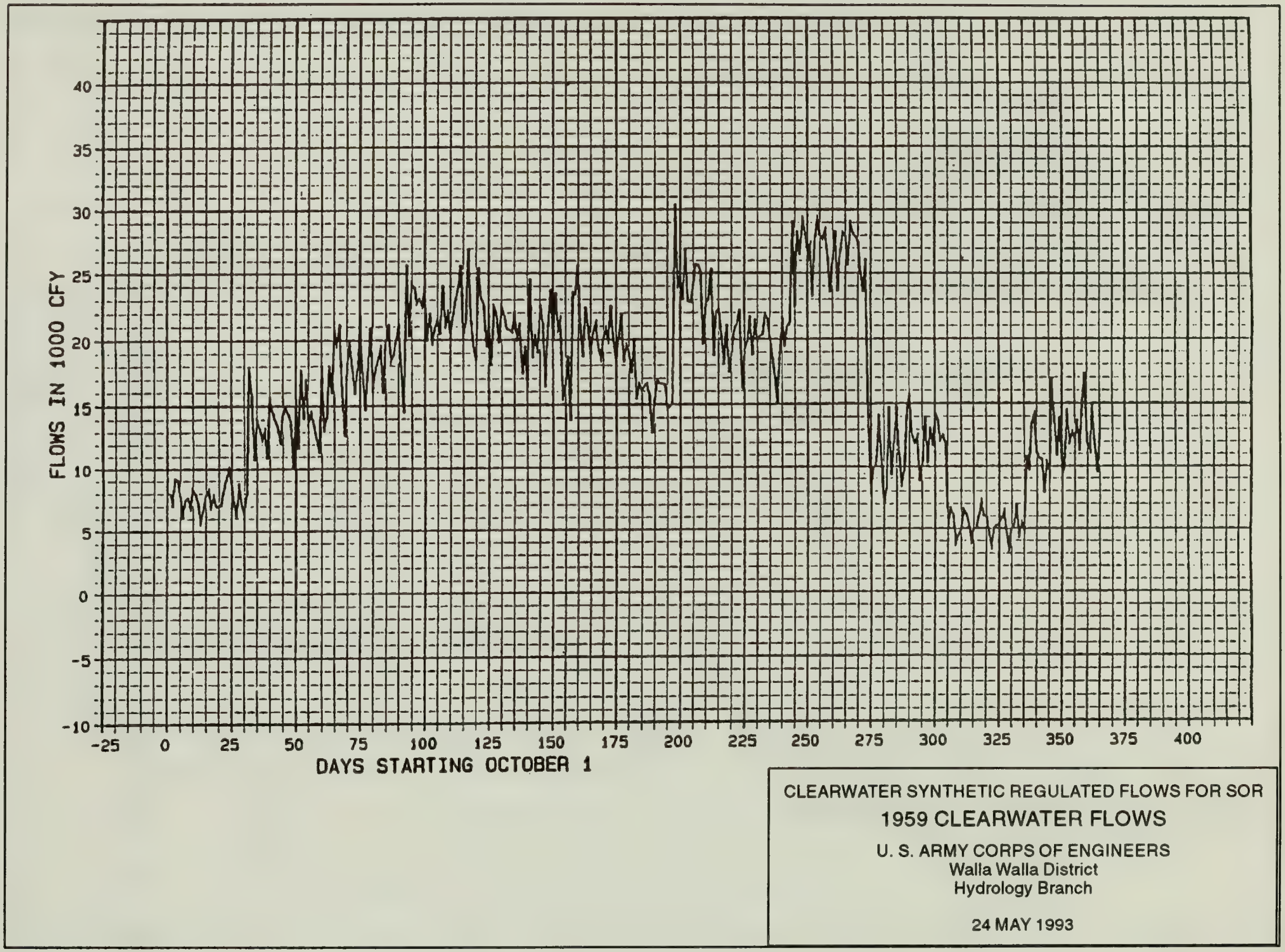


**Figure G–5. Plate 05: 1959 Clearwater Flows**

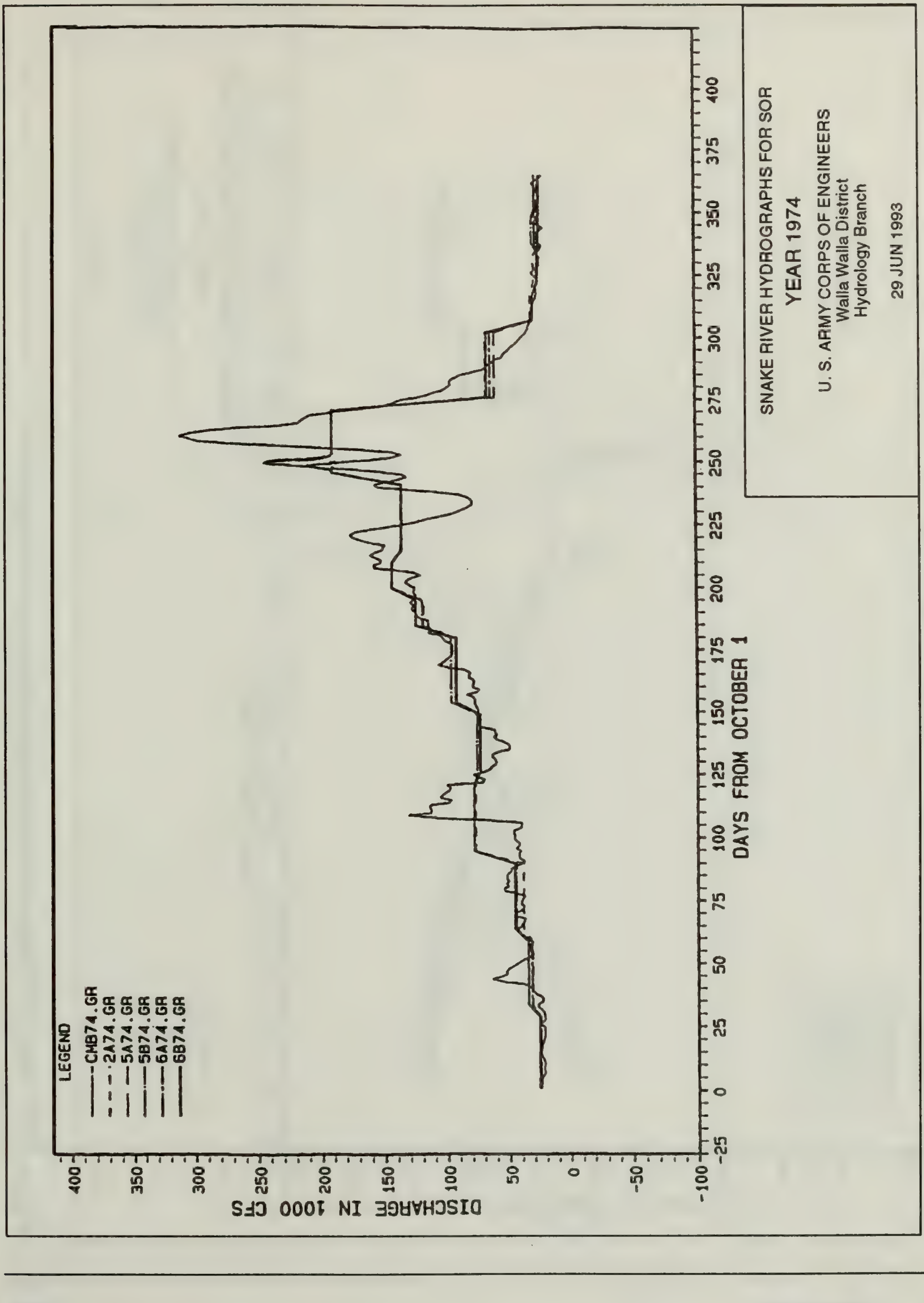


**Figure G–6.** Plate 06: Snake River Hydrographs for SOR Year 1974

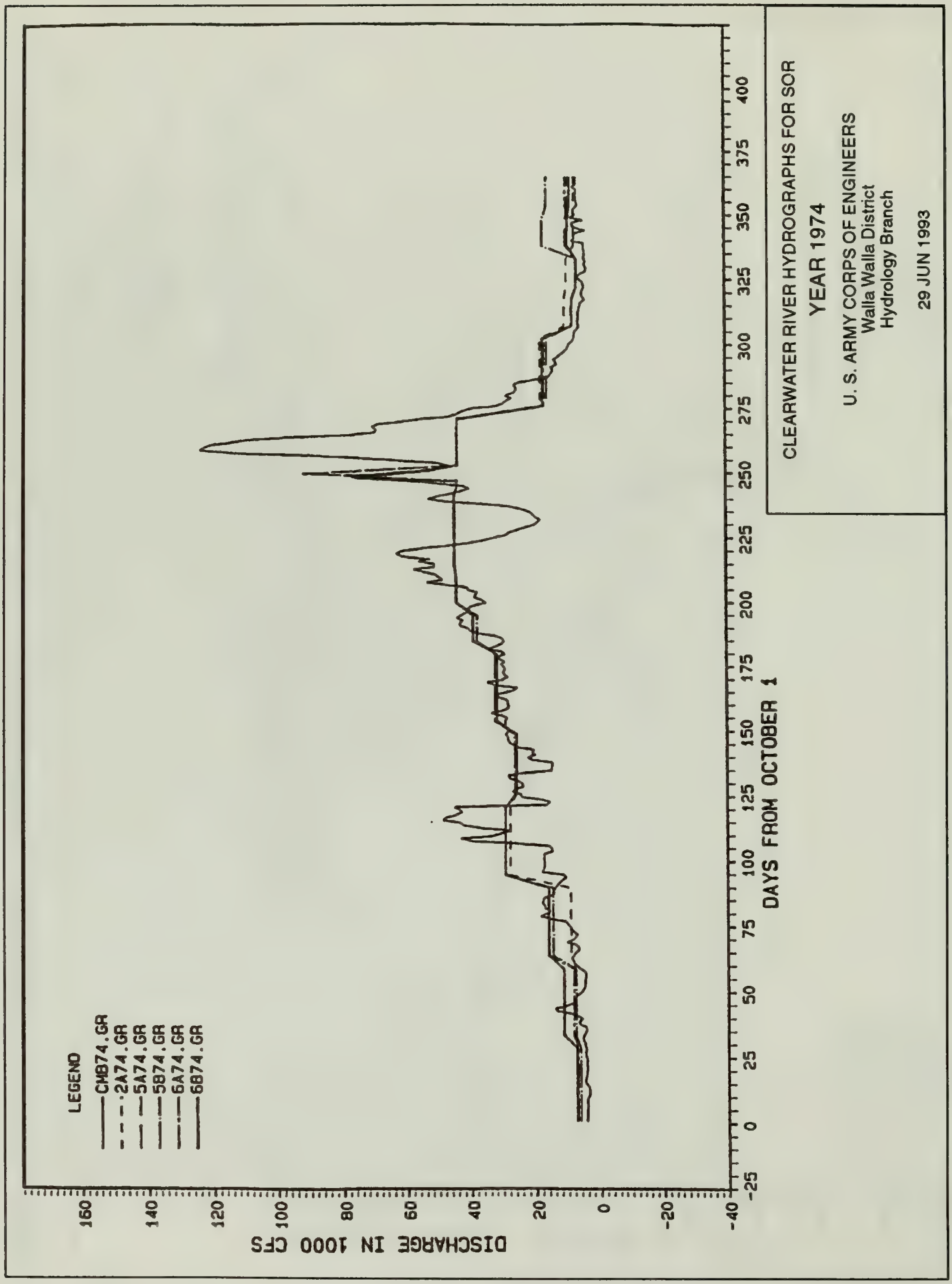


**Figure G–7. Plate 07: Clearwater River Hydrographs for SOR Year 1974**

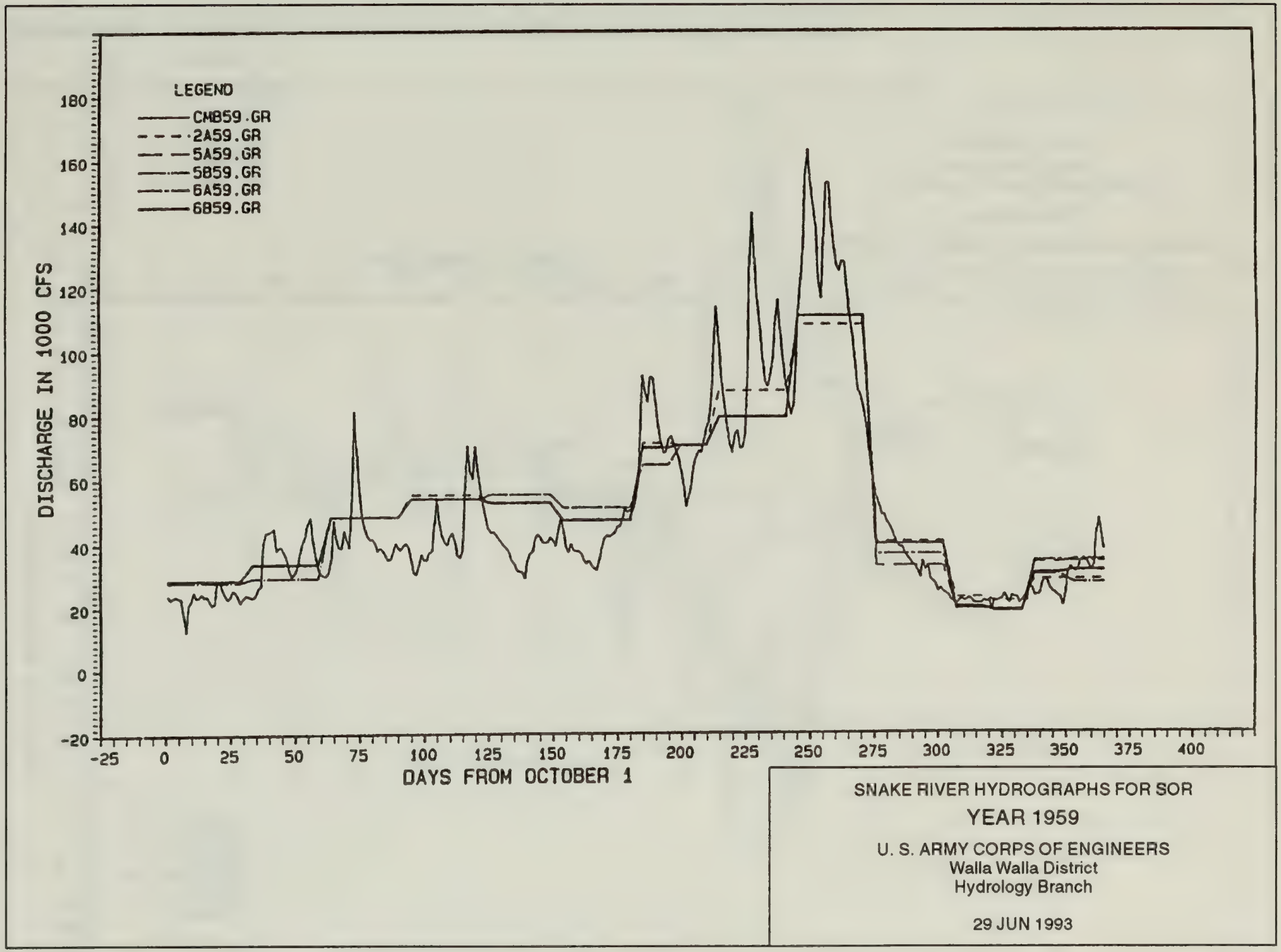


Figure G–8. Plate 08: Snake River Hydrographs for SOR Year 1959

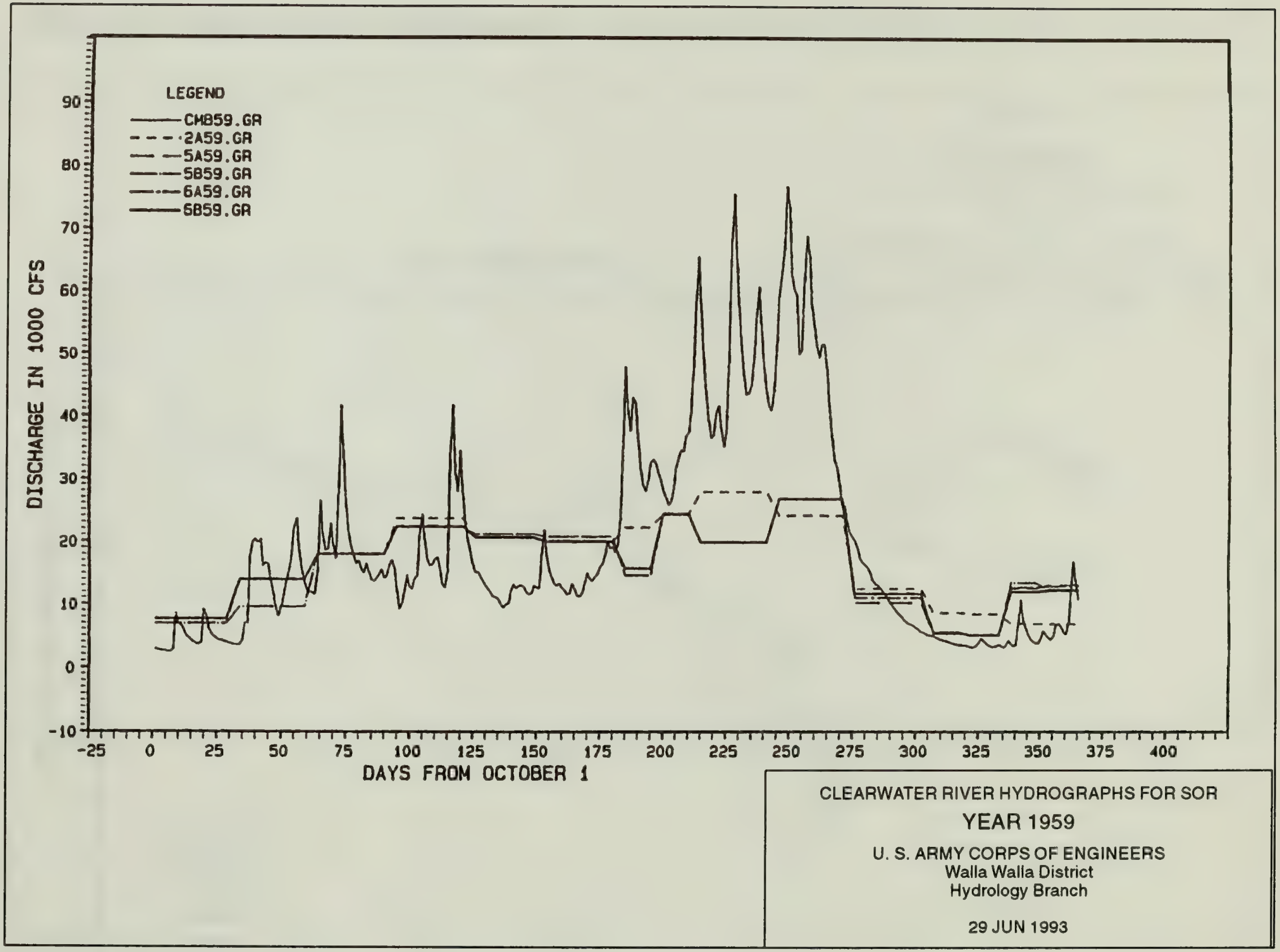


**Figure G–9. Plate 09: Clearwater River Hydrographs for SOR Year 1959**

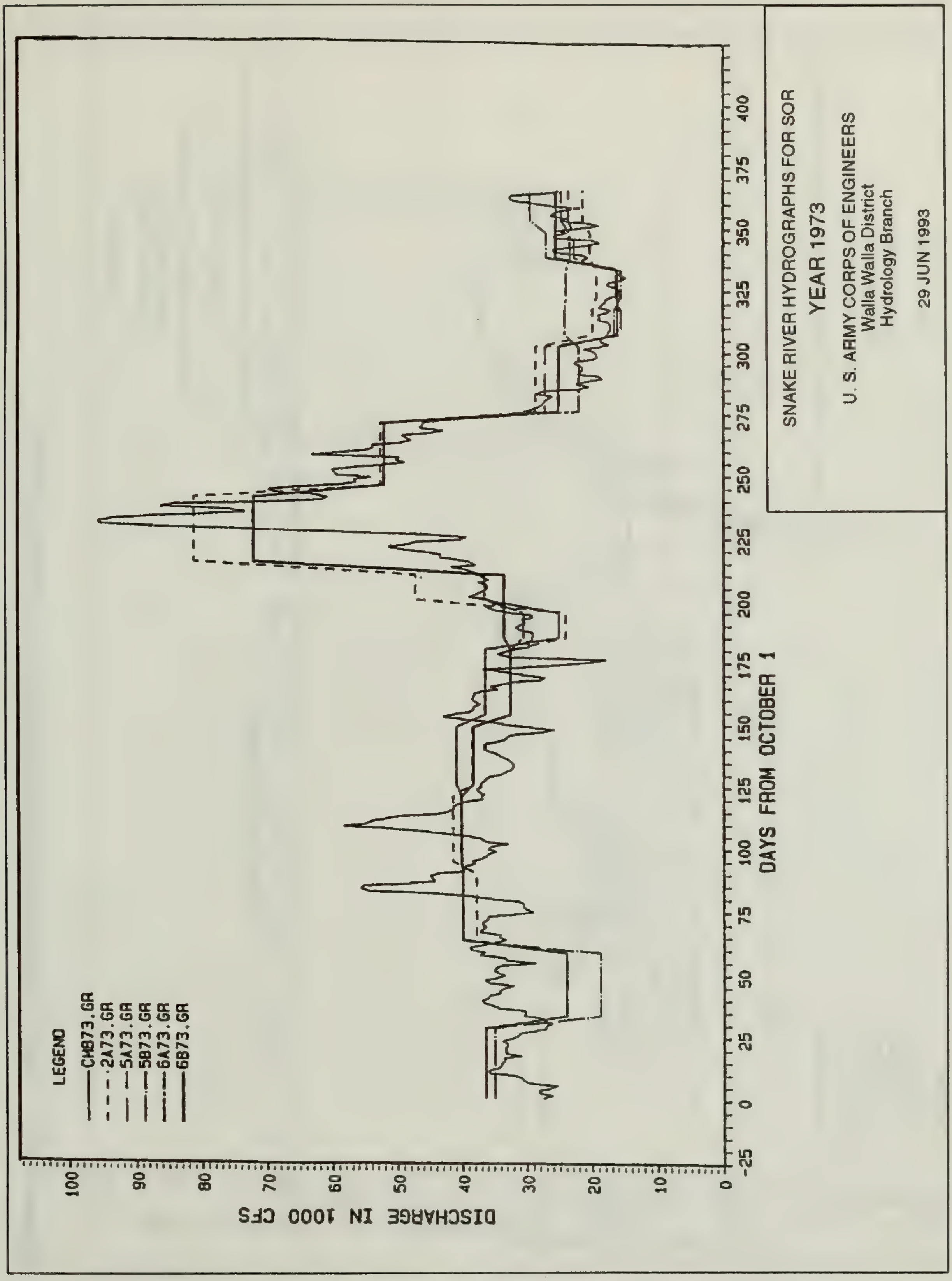


Figure G–10. Plate 10: Snake River Hydrographs for SOR Year 1973

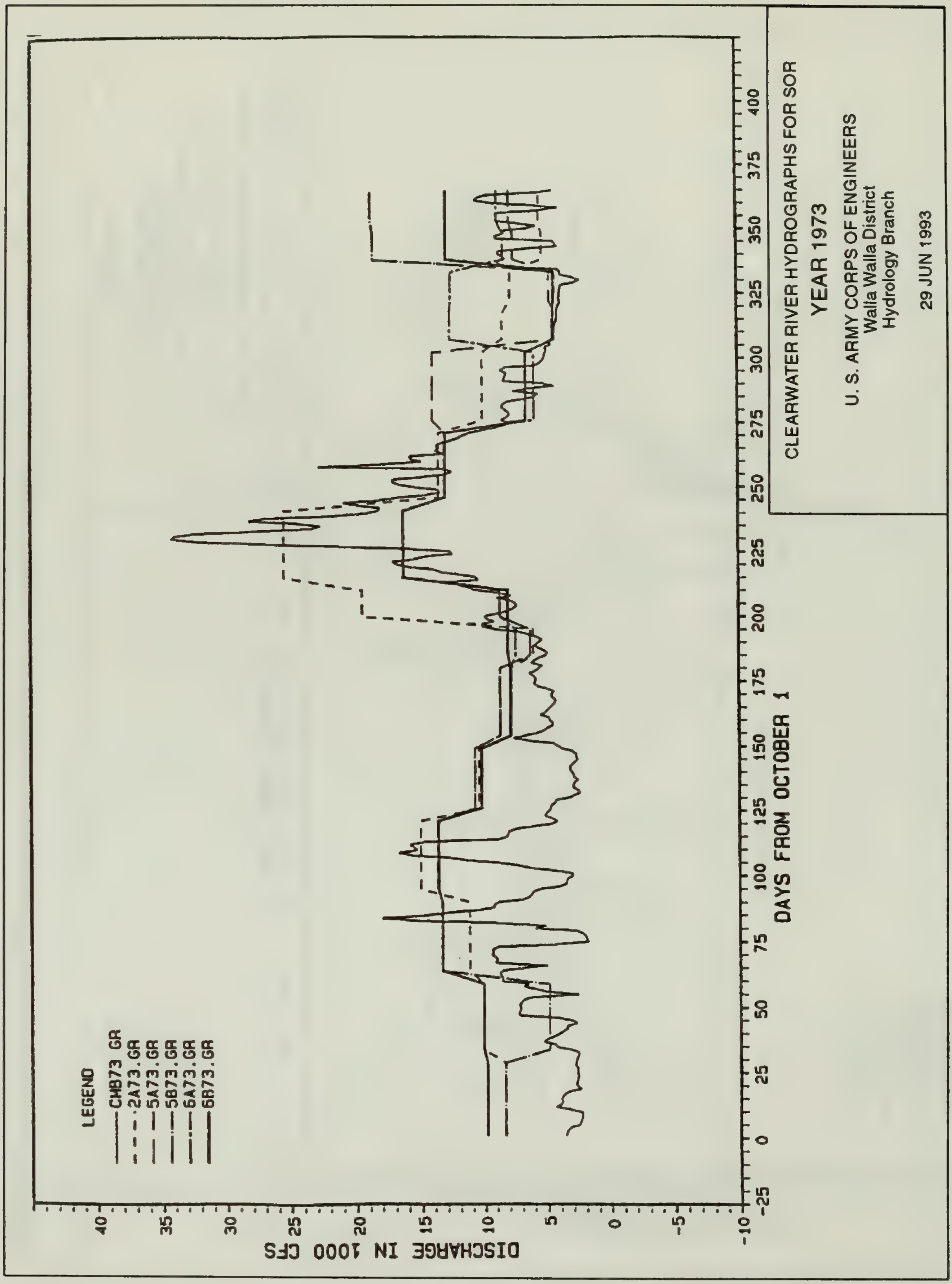


**Figure G–11. Plate 11: Clearwater River Hydrographs for SOR Year 1973**

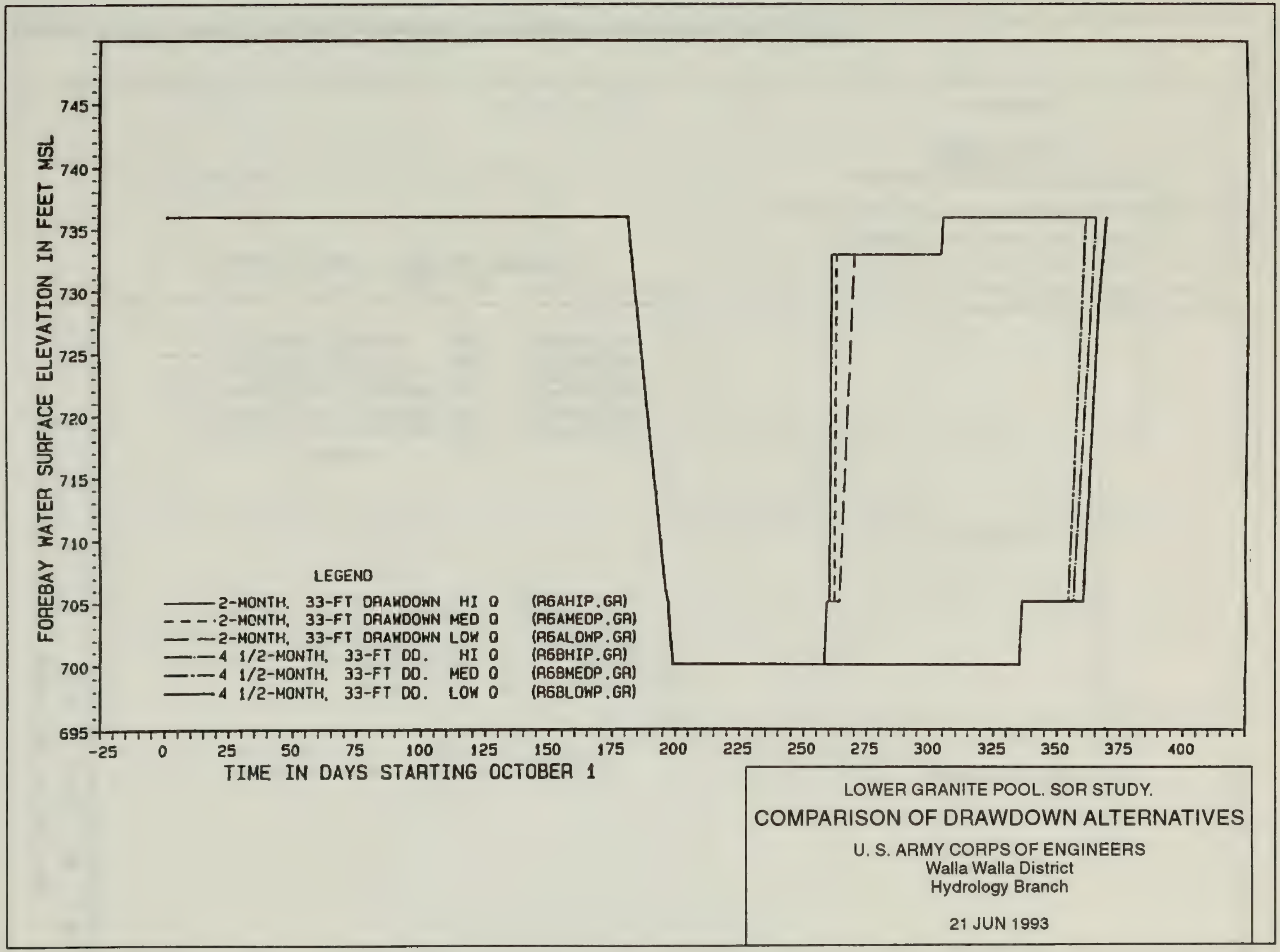


Figure G–12. Plate 12: Comparison of Drawdown Alternatives (Runs R6)

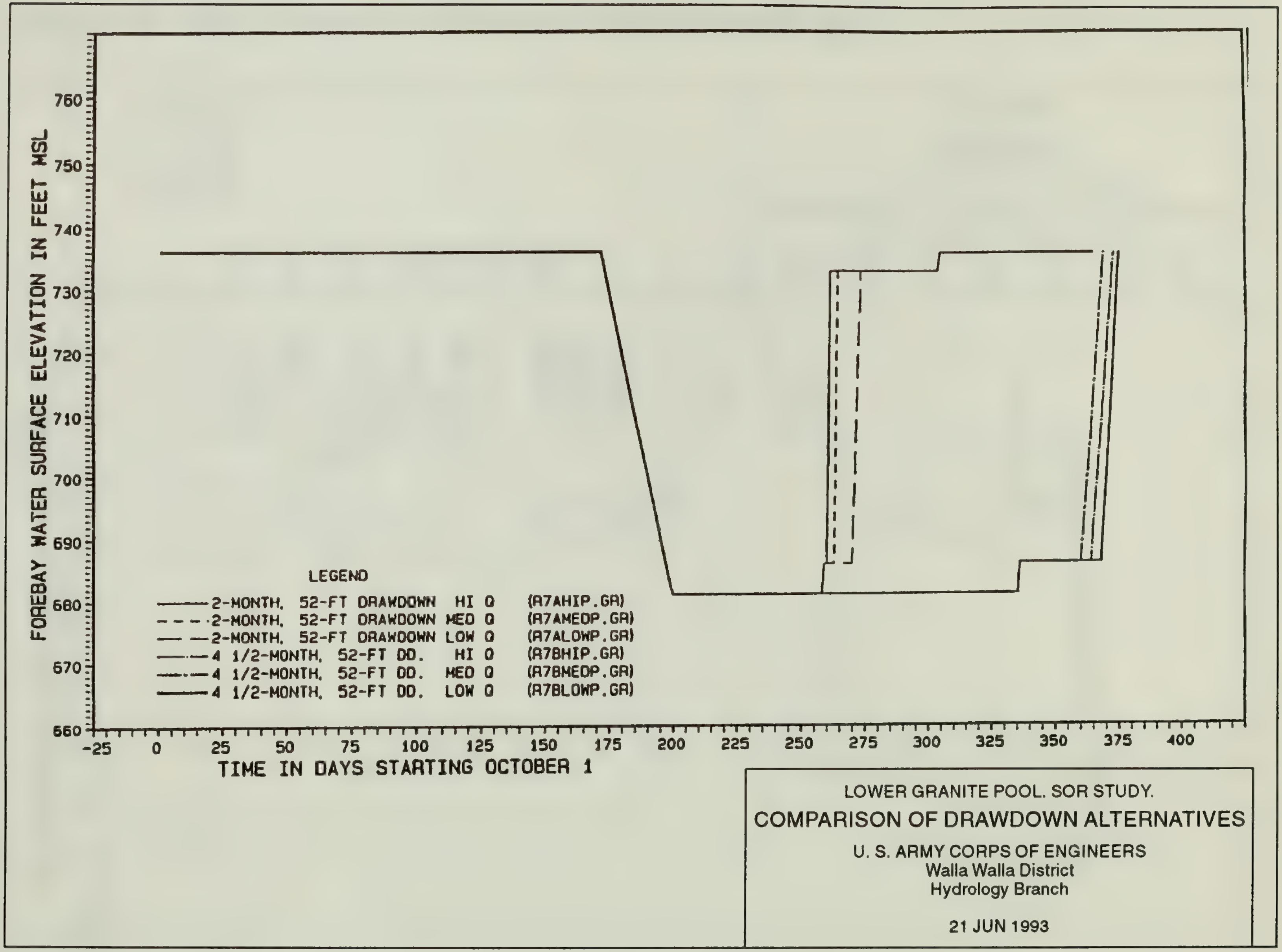


Figure G–13. Plate 13: Comparison of Drawdown Alternatives (Runs R7)

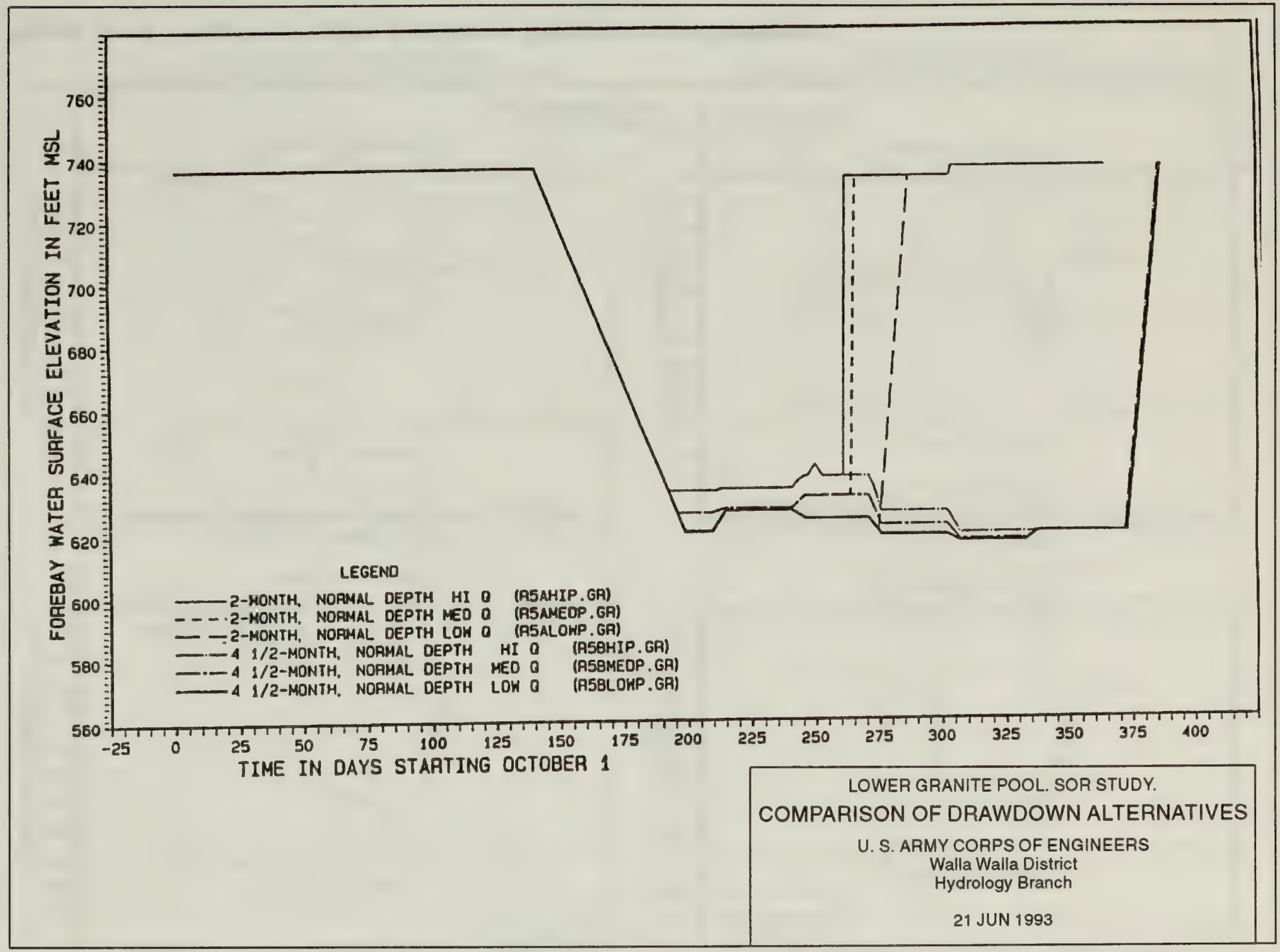


Figure G–14. Plate 14: Comparison of Drawdown Alternatives (Runs R5)

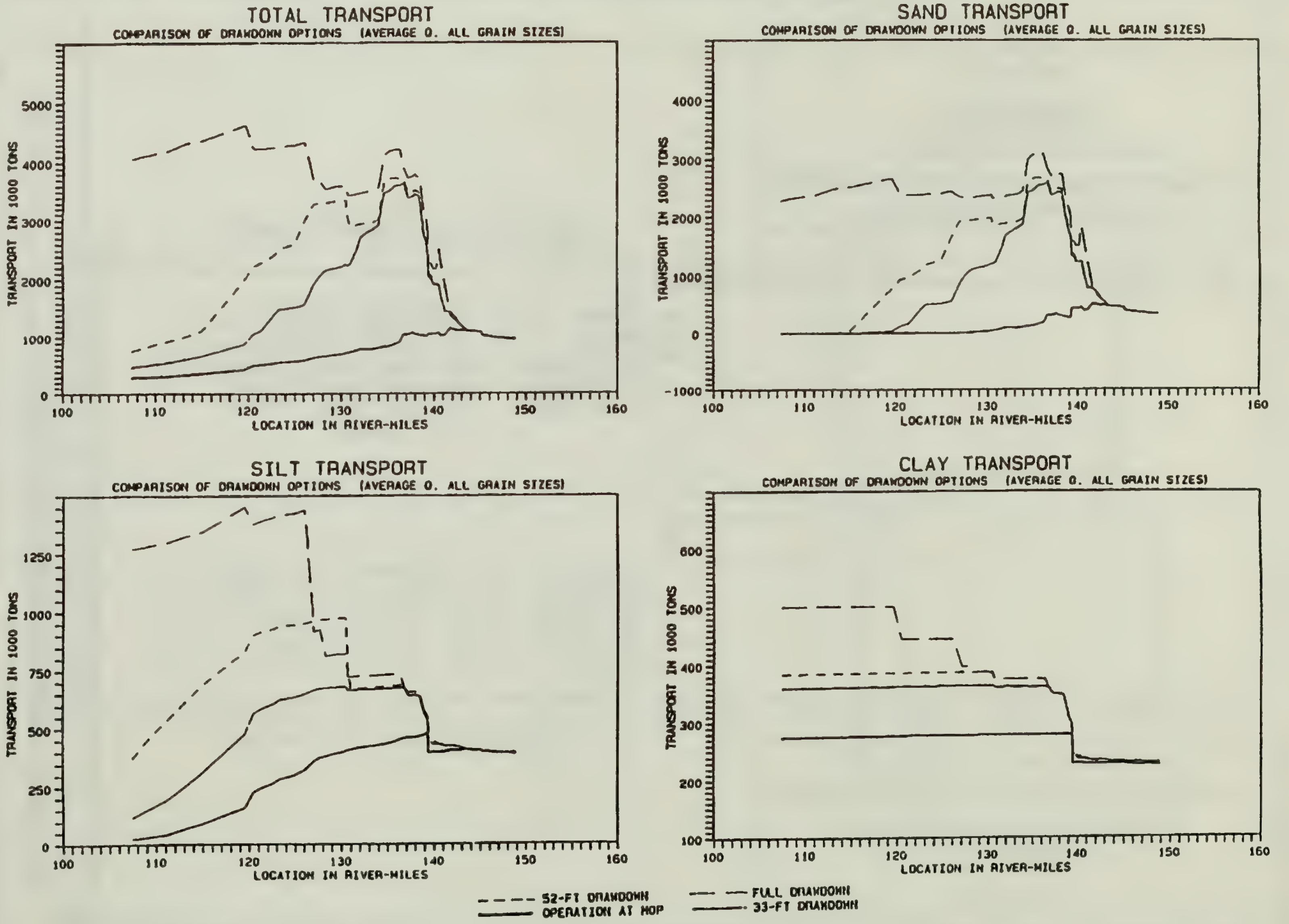


Figure G–15. Plate 15: Predicted Sediment Transport (with Drawdown)

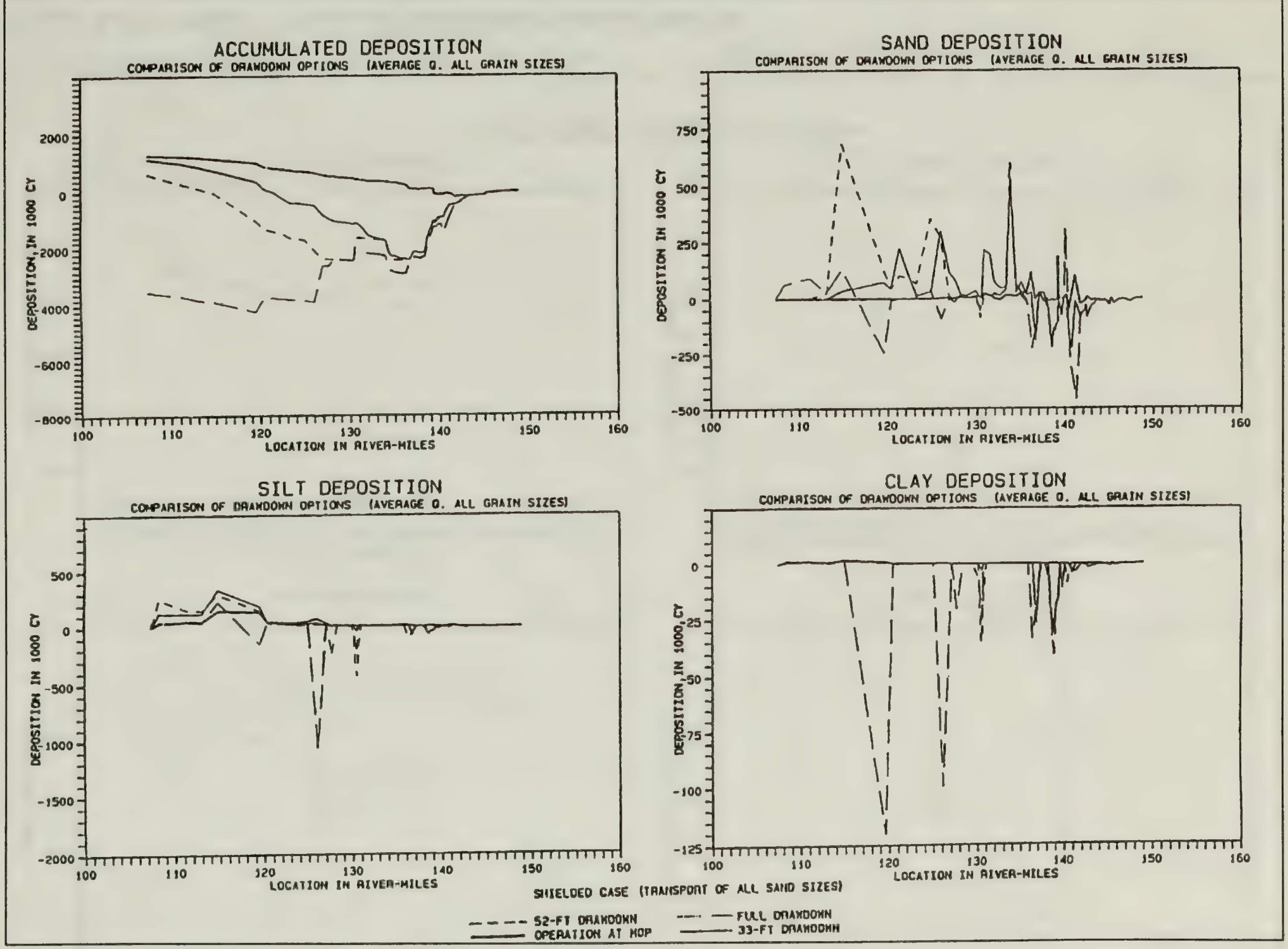


Figure G–16. Plate 16: Predicted Sediment Deposition (with Drawdown)

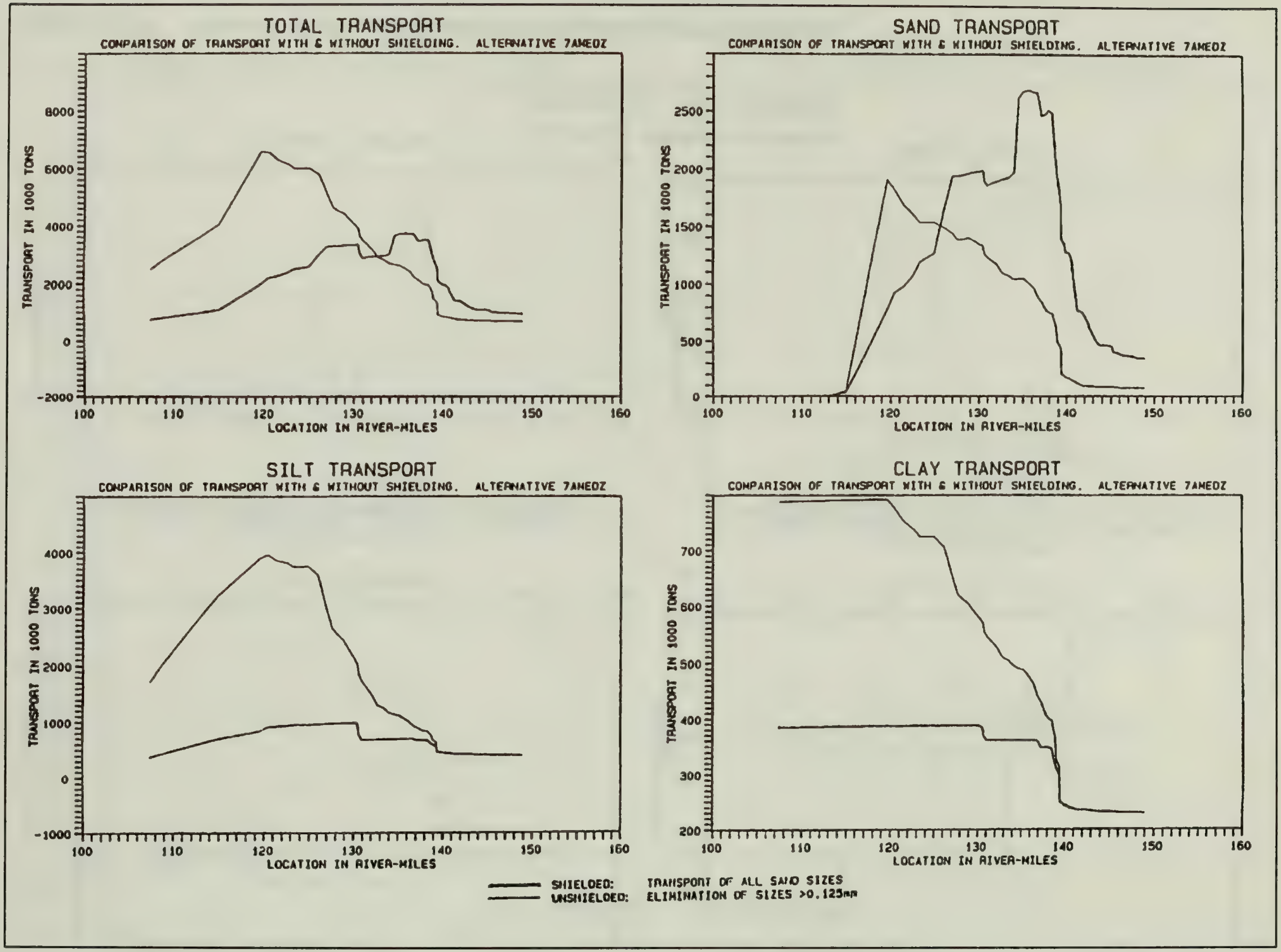


Figure G–17. Plate 17: Predicted Sediments Transport (Alt. 7a)

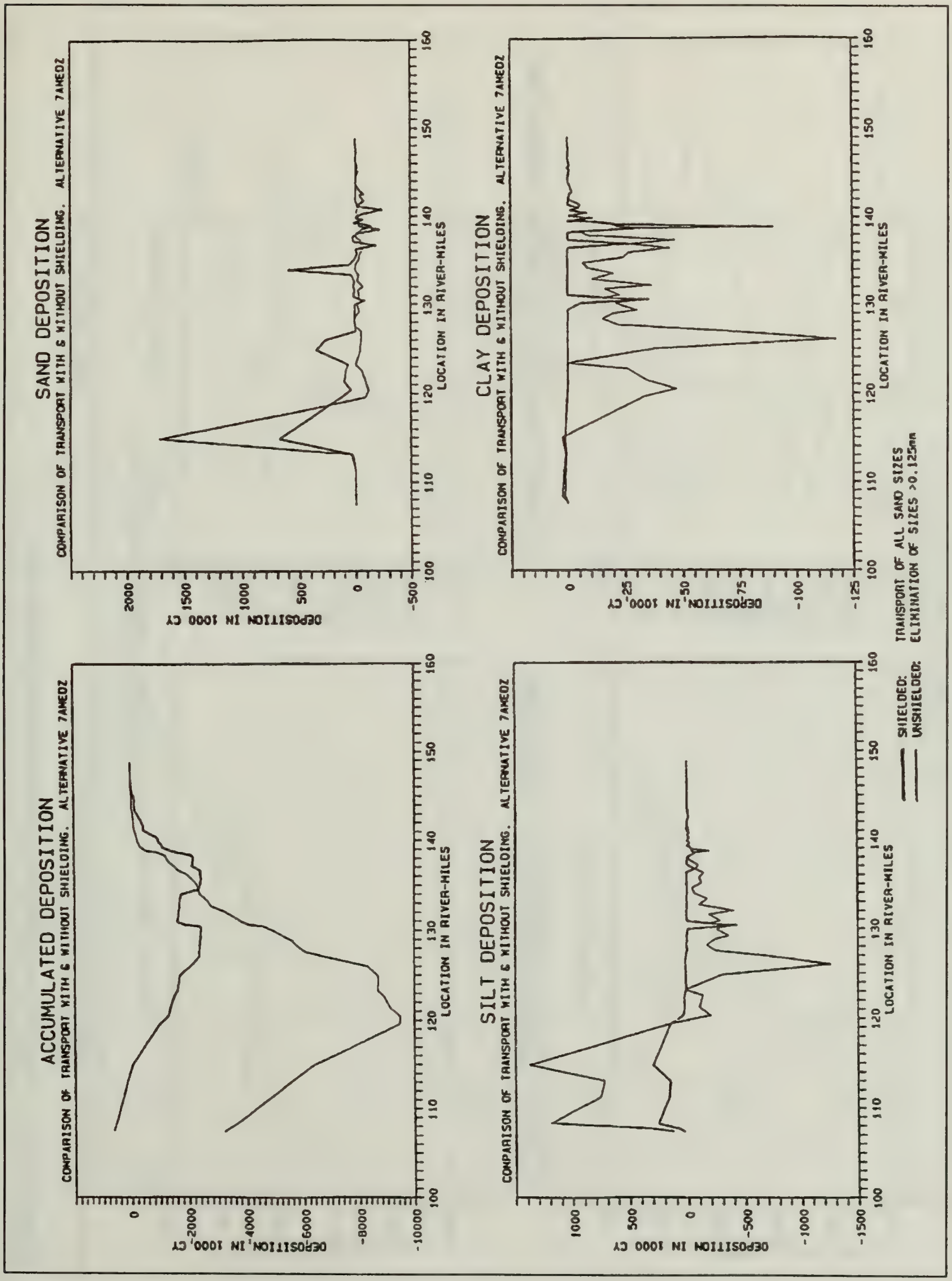


**Figure G–18. Plate 18: Predicted Sediments Deposition (Alt. 7a)**

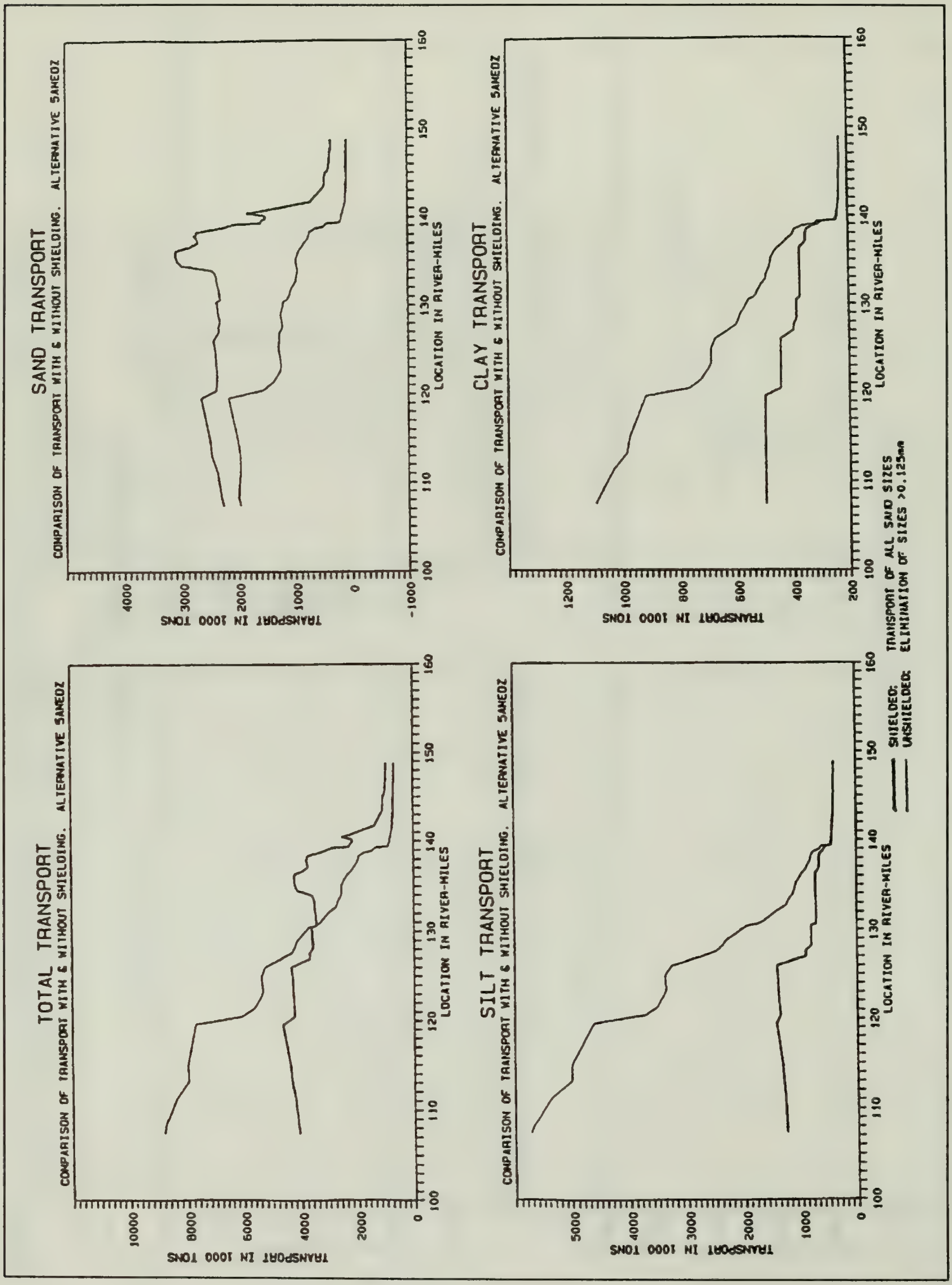


**Figure G–19.** Plate 19: Predicted Sediments Transport (Alt. 5a)

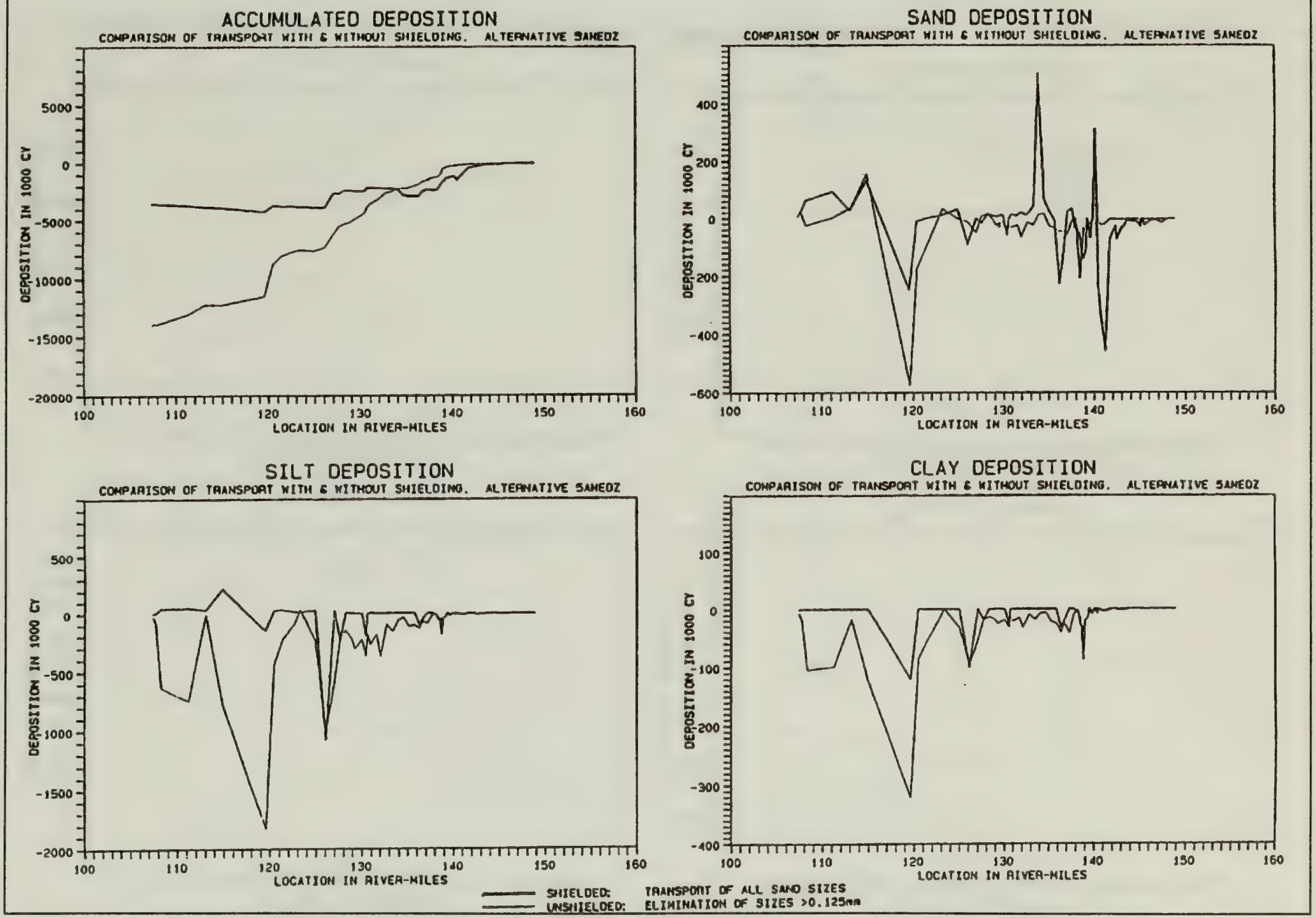


Figure G–20. Plate 20: Predicted Sediments Deposition (Alt. 5a)

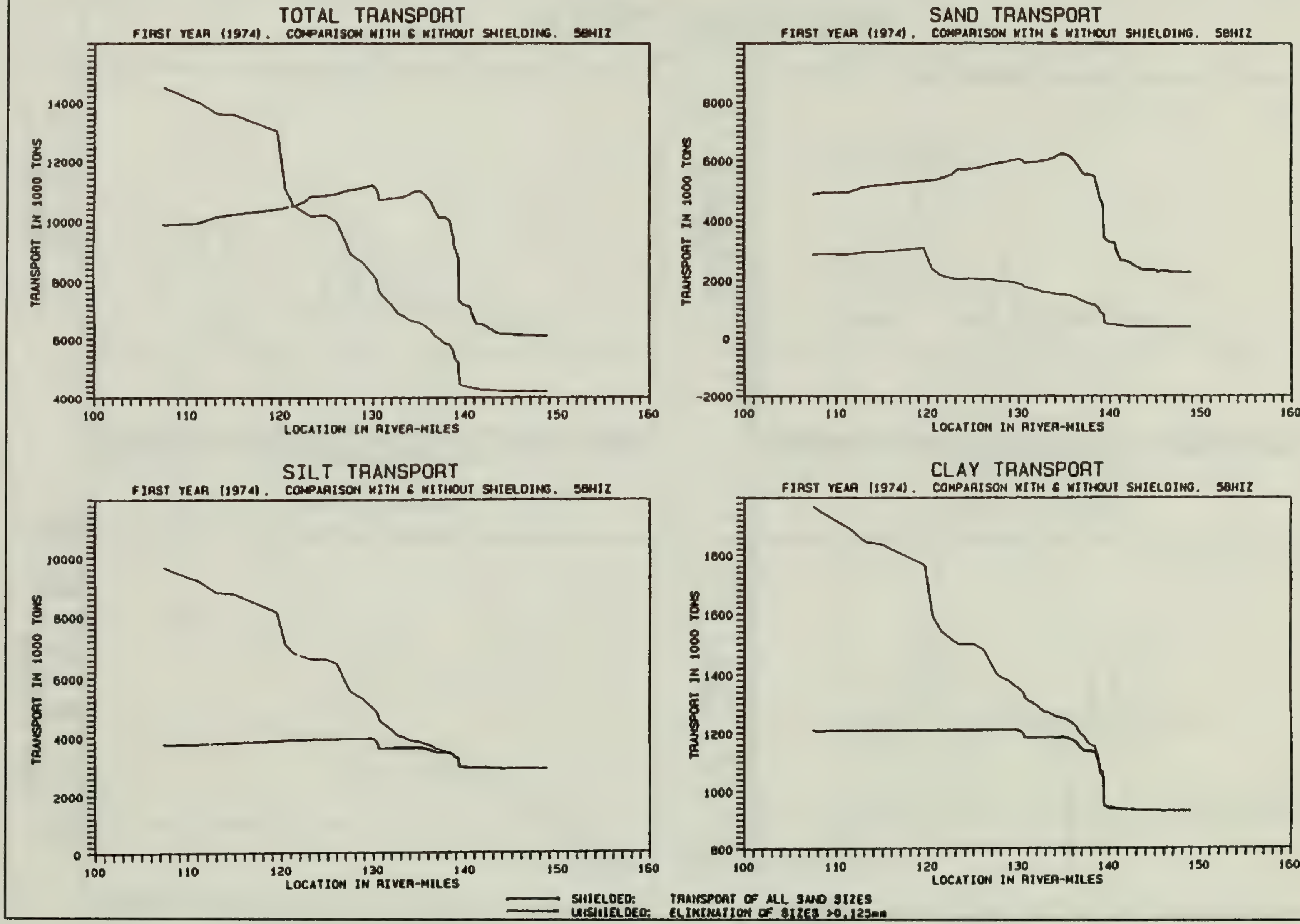


Figure G–21. Plate 21: Predicted Sediments Transport (Alt. 5b), First Year

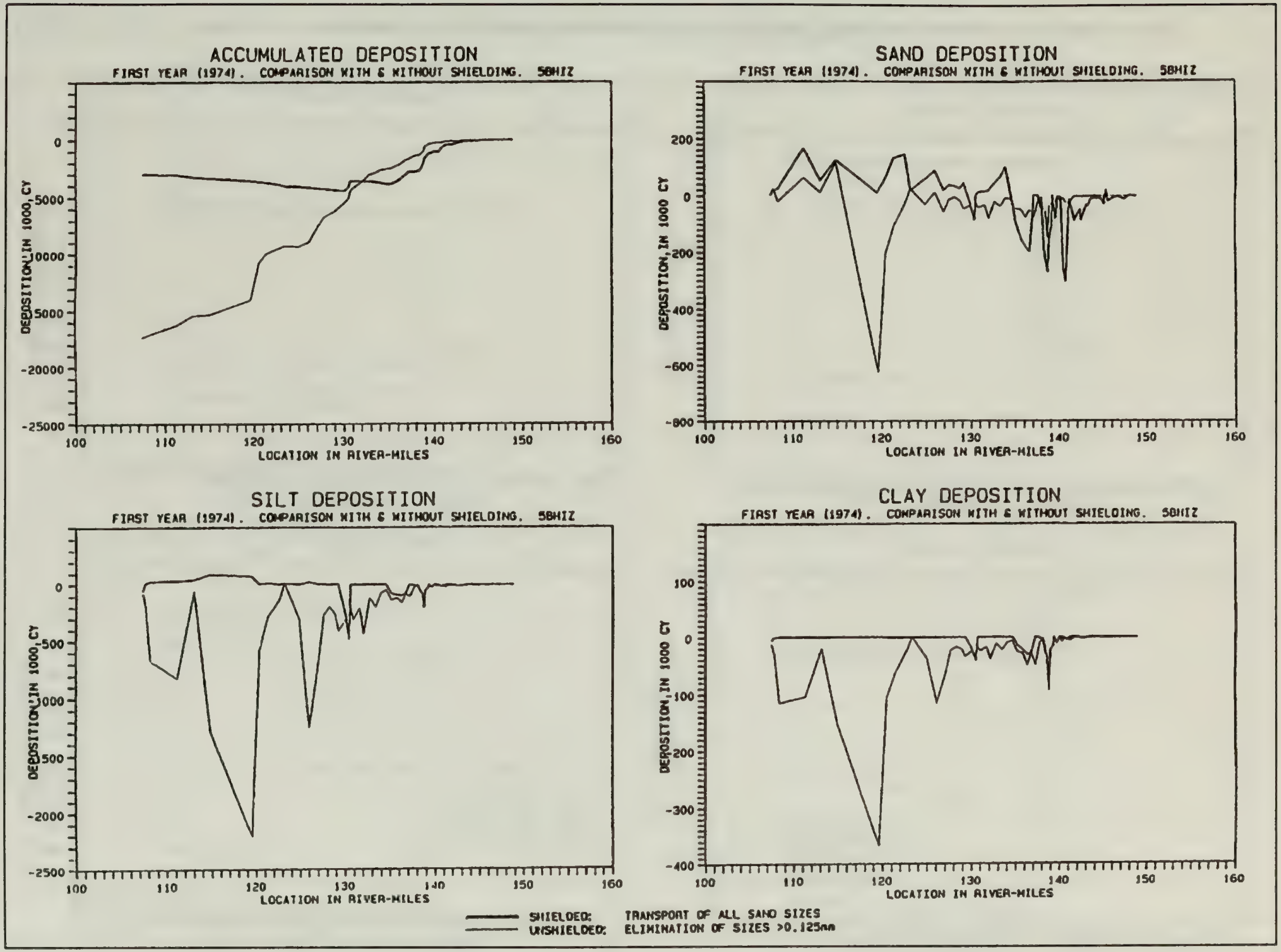


Figure G–22. Plate 22: Predicted Sediments Deposition (Alt. 5b), First Year

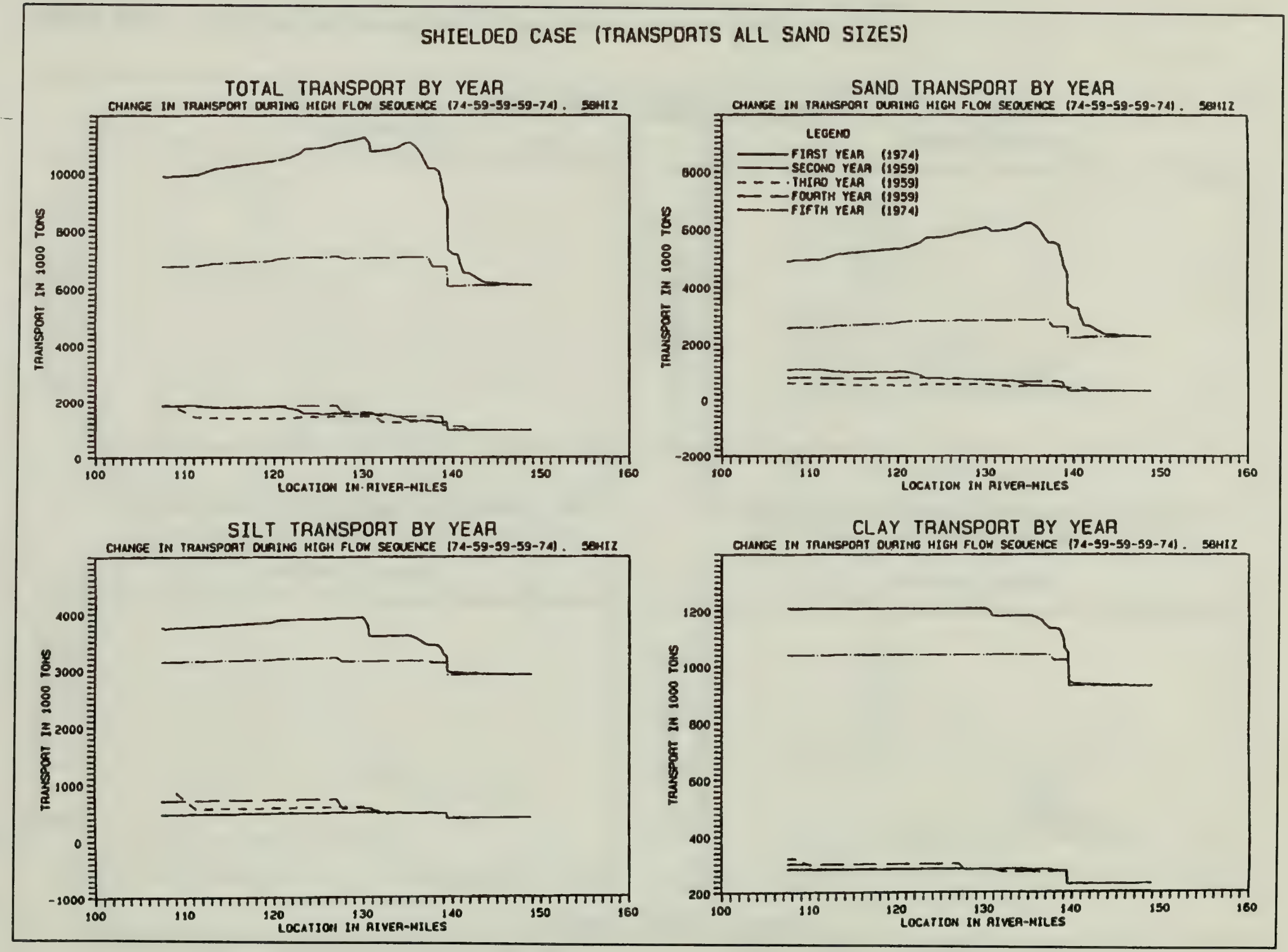


**Figure G–23. Plate 23: Predicted Sediments Transport (Alt. 5b), High Flow Sequence, Shielded Case**

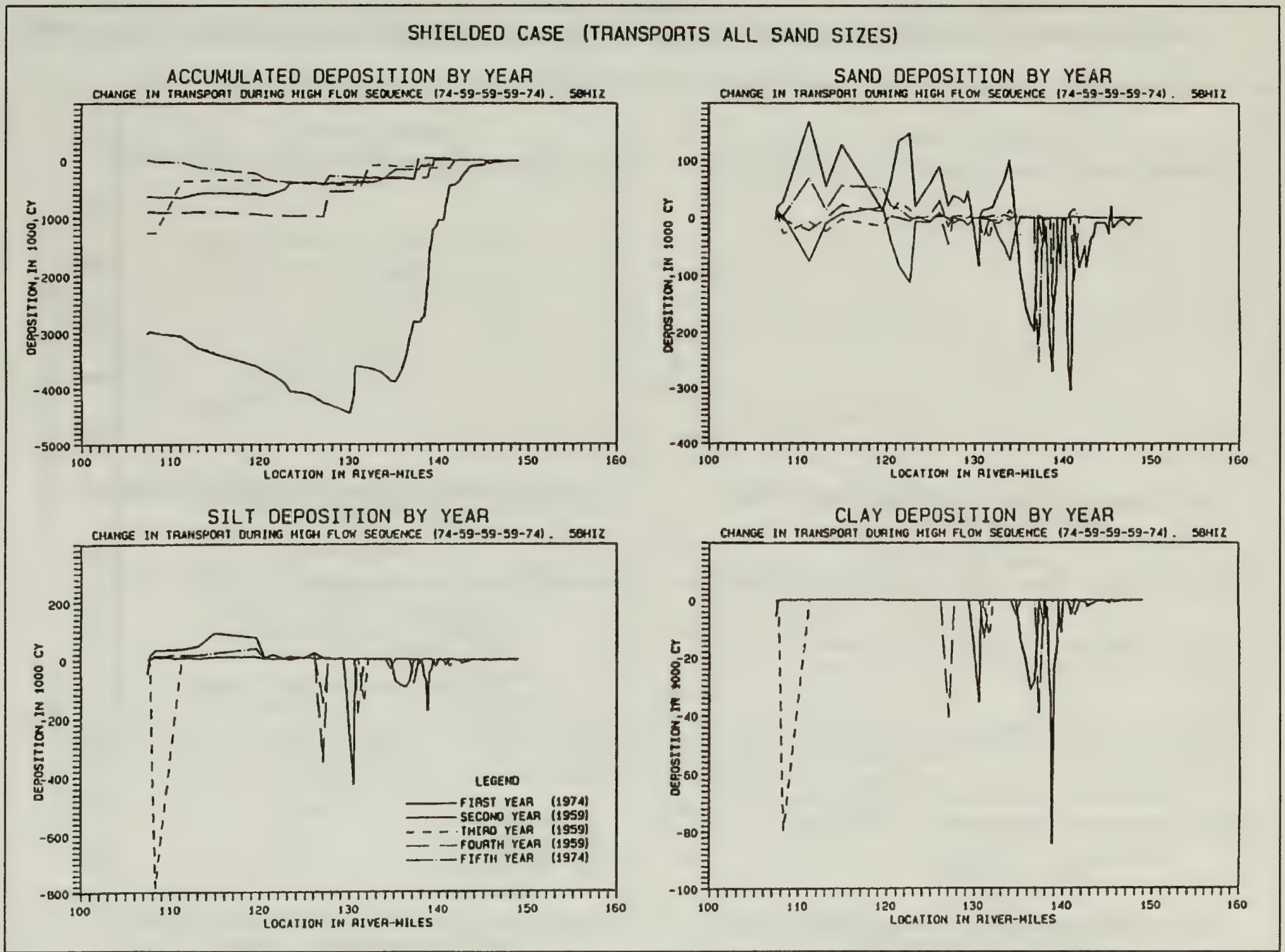


Figure G–24. Plate 24: Predicted Sediments Deposition (Alt. 5b), High Flow Sequence, Shielded Case

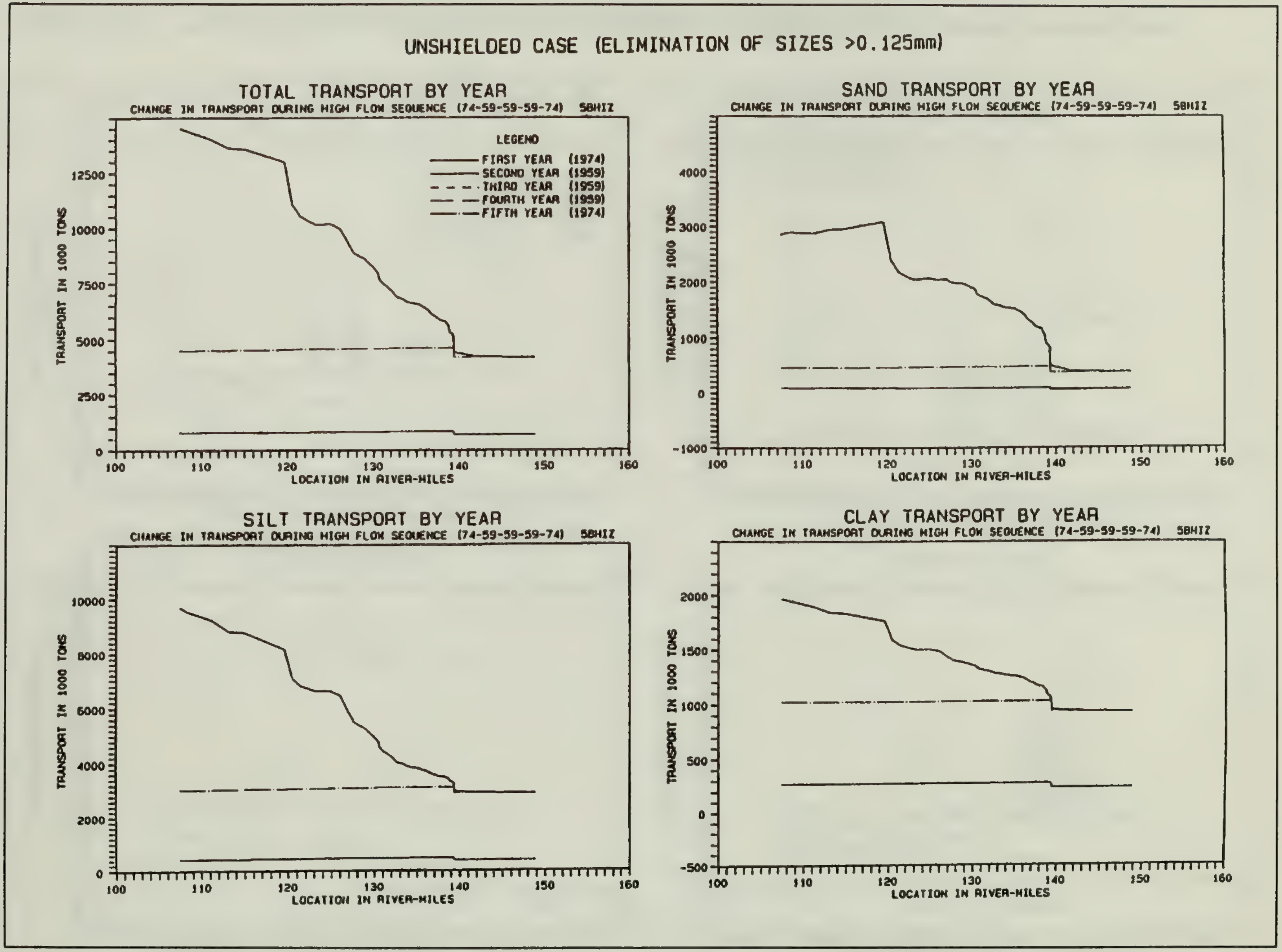


Figure G–25. Plate 25: Predicted Sediments Transport (Alt. 5b), High Flow Sequence, Unshielded Case

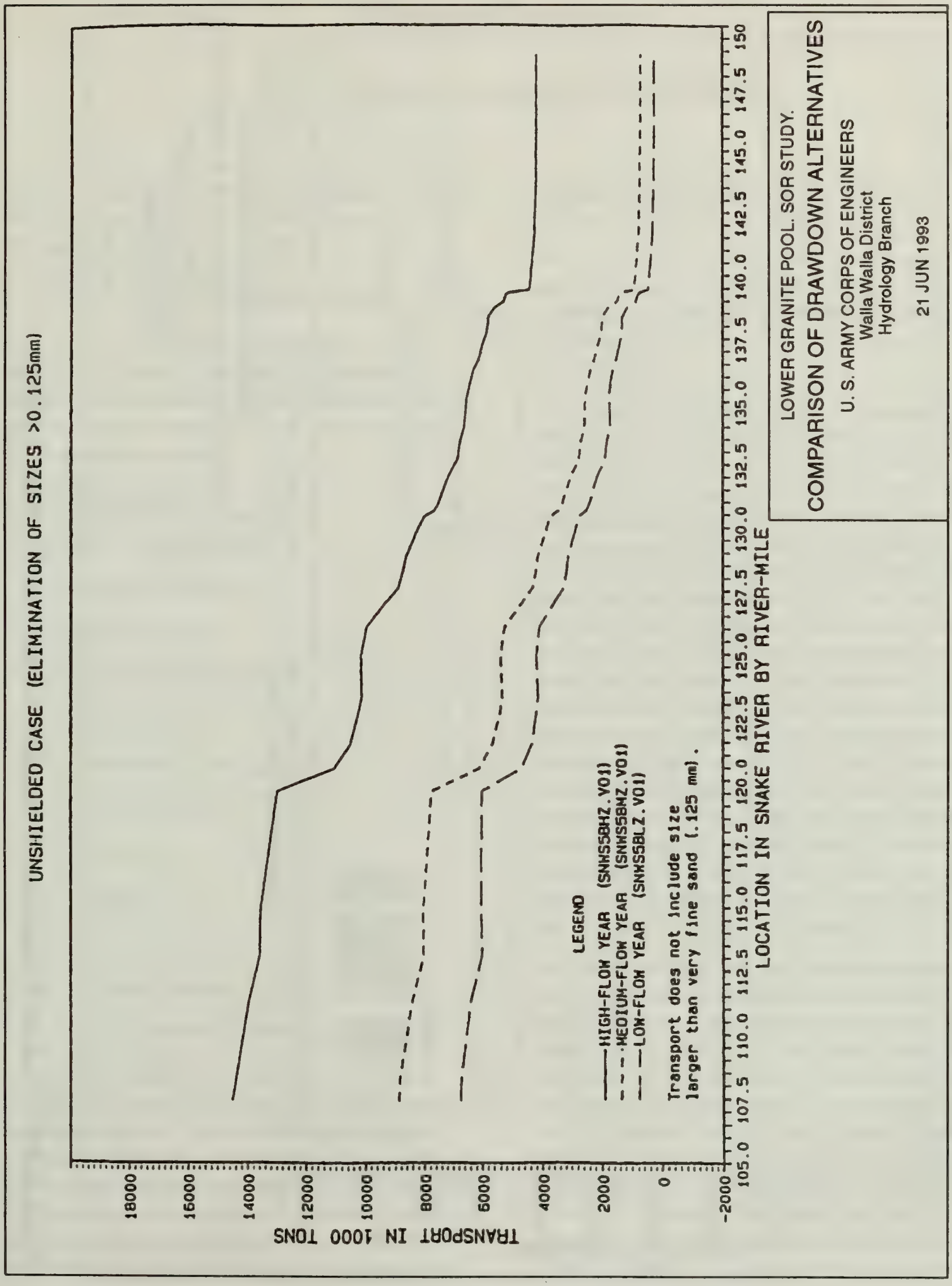


**Figure G-26. Plate 26: Comparison of Drawdown Alternatives (Unshielded Case)**

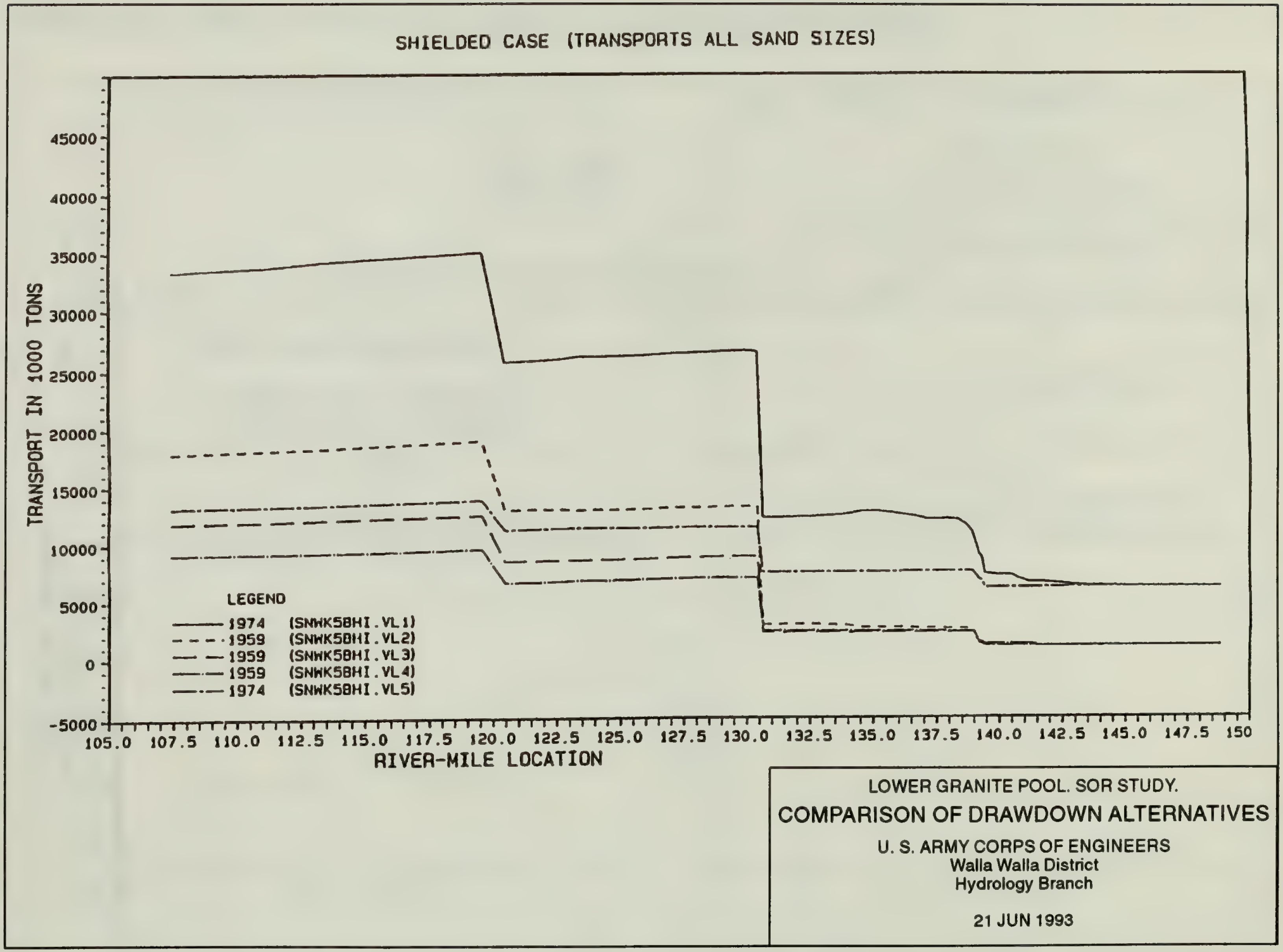


Figure G–27. Plate 27: Comparison of Drawdown Alternatives (Shielded Case)

# TECHNICAL EXHIBIT H

# HEC-5Q MODEL CALIBRATION RESULTS

**NOTE:** This technical exhibit was based on material submitted by Resource Management Associates on November 22, 1992.

## H–1 HEC-5Q MODEL WATER QUALITY

The Columbia River System Operation Review (SOR) and the Mitigation Analysis requires a model study to evaluate effects of alternative operation scenarios on temperature and the following water quality parameters.

Temperature

Total Dissolved Solids

Ammonia Nitrogen

Nitrate Nitrogen

Total Dissolved Phosphorus

Phytoplankton

Carbonaceous BOD

Dissolved Oxygen

Chlorides

Alkalinity

pH

Coliform Bacteria

Up to 3 Organic or Inorganic Suspended Particle Sizes

The HEC-5Q presently includes all of these water quality parameters. The fundamental transport mechanism within the model controlling the fate of Each of these parameters is advection and diffusion. each parameters is assumed to be passively transported with water movement. External sources and sinks of each parameter include point sources and withdrawals, non-point or diffuse sources and exchange with bottom sediments.

Point sources include headwater or tributary inflows and are represented by a flow rate and a corresponding concentration. Withdrawals remove mass at the rate of the outflow times the computed ambient concentration.

Non-point or diffuse sources are represented as an inflow rate / mile and a corresponding concentration. The non-point sources should represent all significant sources of the parameter not identified with a major tributary (point sources) and may include agricultural drainage returns, ground water inflows, atmospheric deposition and shoreline fluxes (e.g., Suspended sediment inflow due to wave action.) Unlike headwater or tributary inflow rates the non-point inflow rate is arbitrary and need not correspond to inflow rate data (IN records) used in the flow routing portion of HEC-5Q. The non-point inflow rate essentially serves as a scaling factor for the non-point inflow quality (e.g. 2.16 cfs/mile @ 1 mg/l= 1 g/day/foot). Since there is no actual flow associated with these sources, the mass added to the system is a function of the difference between the concentration in the inflow and ambient. If a constant mass loading is desired, a high concentration and low flow rate is recommended.

Benthic source and sink rates take two forms. The ammonia and phosphorus models represent the bottom flux as the net rate from the bottom to the water column. The rate in the oxygen model represent a net loss to the bottom. These rates are input as a constant rate per unit of bottom area by the user. The bottom fluxes for heavy metals, dissolved organic chemicals and dioxins and furans (referred to as pollutants in the following sections) utilize a bed model. The bed model tracks the total pollutant mass and pore water concentration within the active bottom sediments. The volume of the active sediments remains constant therefore sediment accumulation due to settling of the particulate results in loss of pollutant by burial. Exchange between the bed and water column is accomplished through diffusion. The rate of transfer is a function of the difference between the dissolved pollutant concentration in the sediment pore water and in the water column. Reversible exchange between the dissolved fraction and the suspended particulate or bottom sediment is represented by a partitioning constant.

Growth, decay, reaeration, volatilization and chemical transformations are represented by first order kinetics. Loss through settling is a function of temperature dependant settling rates and the near bottom concentration of the particulate. For longitudinally segmented reservoirs and stream sections, the near bottom concentration is computed as a function of current velocity using a Rouse distribution. For vertically stratified reservoirs, the vertical distribution is simulated explicitly.

The model simulates total pollutant mass (dissolved and sorbed) and partitions the total into the sorbed and dissolved phase as necessary to compute the various fluxes. (i.e., dissolved for computing volatilization and sorbed for computing settling loss). Biological accumulation by phytoplankton is also represented by a partitioning coefficient. Partitioning between the dissolved and sorbed phase is assumed at equilibrium. The range of processes affecting the concentration of each pollutant is depicted on Figure H−1.

The model representation governing the response of each parameter is presented in the HEC-5Q users manual and in Exhibit H. Exhibit H is intended as an addendum to the users manual.

## H–2 MODEL CALIBRATION AND SENSITIVITY

In the following sections, the processes affecting each water quality parameter will be discussed along with the results of the model calibration and sensitivity.

Model calibration normally involves simulation of period of time when sufficient observed data are available to quantify the water quality of tributary inflows and the water quality at various locations within the reservoirs and stream sections of the river system encompassed by the model.

The water quality data (other than temperature) used for this study were extracted from USGS publications and are shown in Table H−1. The observations are reported as a single value or as a range for given years and reflect Summer and Fall conditions. Data for other periods were ignored since the modeling effort was originally concentrated on the July through September period. The range in values usually represent two and occasionally three observations.

A second data set was used to augment the data shown in Table H−1. The second data set represented long term averages and statistical variations for the Northport and Warrendale Stations on the Columbia River and for the Yakima and Deschutes Rivers. Since these data included measurements for the entire year, the value for calibration was limited.

These data are not sufficient in detail to select a discrete period of time to use for model calibration and validation. Rather, the data were used to estimate typical Summer time concentration for the major tributaries for use under all hydrologic year type. No attempt was made to vary these concentrations over time or as a function of flow rate. The concentration of modeled parameter in each tributary is shown in Table H−2.

No water column data were available (other than non-detects) for parameters such as dioxins (dissolved organic chemicals). The presence of parameters such as dioxin can only be determined by analysis of fish tissue or bottom sediments since dissolved levels are always well below the detectable limit. For these pollutants, estimates of relative concentration were made based on the type of industry and agricultural practice within the watershed (e.g., high pesticide residual in the Snake River inflow to Brownlee to reflect the relative high component of return water). The relative magnitude of the estimated concentrations of dioxin and DDE is completely arbitrary and does not attempt to reflect actual concentrations. Rather the concentration should be viewed as a tracer concentration to estimate relative concentrations with the river system.

Table H–2 includes pulp mill discharge (Tributary #12). This discharge was used to demonstrate how a point loading of a pollutant would be simulated. Again, it should be stressed that the concentration of the pollutant (dioxin) is completely arbitrary and does not attempt to reflect actual conditions.

The final tributary labeled non point loading is an estimate of agricultural return flow from small ungauged tributaries.

An important use of the prototype data is the specification of the initial water quality conditions within the river-reservoir system at the beginning of the simulation. Due to the combined volume (nearly 20 million acre feet) of the 19 simulated reservoirs, the replacement time of this volume is nearly as long as the simulation period. Therefore, the initial conditions affect simulation results in the lower reaches for much of the simulation period. The data presented in Table H–1 and daily temperature data were used to estimate uniform initial quality in all reservoirs except Grand Coulee, Brownlee and Dworshak Reservoirs. Grand Coulee is represented as a longitudinally segmented reservoir and variable initial temperature was required to reflect the attenuation through the reservoir of seasonable variation in inflow temperature. Variations in heavy metals (and suspended particulates) were required to reflect loss of sorbed metals due to settling of particulate material within the reservoir. Vertical variation in Dworshak temperature are important to simulate the selective withdrawal of cold water. The initial temperature profile was based on temperature profile data. The vertical temperature distribution in Brownlee was estimated from inflow and outflow temperature. Uniform initial concentration of all other parameters were assumed for these three reservoirs. No initial conditions (other than pollutant concentration in the sediment pore water) are required for stream reaches since steady state is assumed initial.

In the following sections, the results of the model calibration and sensitivity analysis are discussed, along with the processes which control the dynamics of each parameter. Considerations and limitations as to the model's use are also discussed. The calibration and sensitivity results are presented as concentration profiles. Two sets of profiles are included and represent conditions in the Columbia River from below Bonneville to Northport and from below Bonneville up the Snake River to Brownlee Dam. The profile plots include the reservoir dam control point as reference. The portion of the plots below river mile 290 (from below Bonneville to McNary Dam) are identical. McNary Reservoir is divided into parallel Columbia and Snake River sections.

The calibration plots show the computed profile near the end of July (day 210), August (day 240) and September (day 270). The sensitivity plots compare computed profiles for the end of August only. The plot routine utilizes a partial set of computed results in that only results at selected points are saved. This partial data set results in slightly irregular plots. The abrupt vertical displacements reflect confluences and major tributary inflows.

## H–3 TEMPERATURE

Water temperature is controlled by inflow temperatures, degree of stratification within the reservoirs and heat exchange at the surface. Initial temperature within the system reservoirs is very important. Particularly in Lake Roosevelt reservoir because of its large volume and Dworshak Reservoir since it controls the pool of cold water available for cooling the Lower Snake River System.

Time variable inflow temperatures were specified based on continuous data from several tributaries (Columbia River at Northport, Salmon River, Clearwater River, Grande Ronde River) for several years (1978, 1979 1980 and 1991). The early attempt at correlating inflow temperature to equilibrium temperature was abandoned. A correlation is observed during low flow summer conditions but does not hold during the spring and early summer high runoff period. During this high flow period, snow melt constitutes the major component of flow. Warmer weather increases the flow rate by increasing the rate of melting while the temperature remains nearly unchanged. The equilibrium approach may result in wide temperature variations during high runoff periods which are not observed in the data.

Heat exchange at the water surface is controlled by meteorological conditions and physical processes which are well understood and documented. None of these processes are subject to adjustment during calibration.

Accurate simulation of water temperature relies on specification of good initial temperature, good weather data and realistic inflow temperatures. Temperature calibration is limited to adjusting vertical mixing coefficients to control stratification in Dworshak and Brownlee Reservoirs.

The model has been shown to adequately represent the thermal responses throughout the river system for summer months of 1984, 1985 and 1990. The temperature model capabilities and results have been presented as time series plots of computed and observed temperatures below many reservoirs within the system. These results have been presented previously in in–house notes on model calibration and are not included here. Profiles of temperature however have been included to provide some insights into how the water temperature changes as it flows downstream.

Referring to Figure H–2 a general heating trend is observed in the mid-Columbia for all periods with the most rapid heating occurring early in the simulation period when Grand Coulee releases are well below the equilibrium temperature. The day 210 results also show the thermal gradient above Grand Coulee Dam (mile 600 to 700). This gradient reflects the attenuation of the increasing temperature of the inflow and reflects initial conditions to some extent. Gradients in the Snake and Lower Columbia Rivers are fairly flat with some heating below the Clearwater inflow (mile 470). The temperature discontinuities at the Snake-Columbia River Confluence (mile 290-McNary Dam) and at the Snake-Clearwater River Confluence (mile 470) is clearly evident. The effects of the Salmon River inflow (mile 495) can also be seen. The effect of all other tributaries is too small to be observed in the temperature results.

## H–4 TDS, CHLORIDES AND ALKALINITY

Total dissolved solids (TDS), chlorides and alkalinity are all treated as conservative. The concentrations of these parameters are dependent entirely upon the concentration of inflows, evaporation and advection and diffusion. None of these processes are subject to adjustment during model calibration. Rather, the model results serve as a confirmation of model inputs including the model representation of the stream-reservoir system.

The model results for these three parameters are shown in Figures H–3, H–4, and H–5. Included in each figure is the range of observed concentrations at Vernita Bridge (mile 390) and below Bonneville (mile 140) on the Columbia River and at Hells Canyon (mile 570) and Burbank (mile 330) on the Snake River. These results show that range in observed values generally bracket the simulation results which indicates that headwater and tributary data are consistent with the in-system data.

These results clearly show the dominance of the quality of the headwater inflow to Grand Coulee on the mid and lower Columbia River. Very little variation is computed in these reaches due to tributary inflow. The lack of change is also due to the fact that the water quality of the tributaries to the Columbia are generally similar to the headwater above Grand Coulee with the possible exception of the Yakima and John Day Rivers basins (although the flows from these two tributaries are relatively small). Conversely, the Snake River plots show the importance of inflow from the Clearwater (mile 470) and Salmon (mile 495) Rivers. These streams provide a supply of generally high quality water to dilute the lesser quality main stem Snake River water flow into Brownlee Reservoir. During periods of low natural runoff, the waters of Dworshak Reservoir provide additional dilution capacity. The impacts of the Dworshak release rate on Snake River water quality can be seen in the day 240 plot between river miles 350 and 410. The elevated concentration of each parameter is a direct result of decreased Dworshak Reservoir releases during the first 20 days of August.

## H–5 PLANT NUTRIENTS AND PHYTOPLANKTON

Plant nutrients include ammonia and nitrate nitrogen and dissolved ortho phosphate phosphorus. Sources of ammonia and phosphate include releases from the bottom sediments. Uptake of nutrient associated with phytoplankton growth is the only sink considered. The transformation of ammonia to nitrate is computed as a function of first order bacterial oxydation. Algal growth is computed using the limiting nutrient approach. The limiting effect of light considers the light attenuation characteristics of the water and the shading effects of phytoplankton and suspended particulate are considered in the computation.

The results shown in Figures H–6 through H–9 are the computed profiles of the three nutrients and phytoplankton. These results reflect model coefficient values which are typical of those reported in the literature. The plots of computed nutrients in the Columbia River continues the trend of insensitivity to tributary inflows and other sources. Concentrations of all nutrients above the Snake River confluence are at very low levels and conform with the observed data. These low levels generally suggest that there is no significant potential for excessive phytoplankton growth.

The nutrient plots for the Snake River also continue the trend of relative high concentrations and the importance of dilution on Snake River quality. The simulated results exhibit the same general trends as the observed data with the exception of ammonia. The increase in ammonia in the four lower Snake River reservoirs (mile 330 to 470) is not seen in the observed data and may result from too high a benthic source rate or excessive non-point loadings. This discrepancy will be resolved before delivery of the final model.

The levels of plant nutrients are sufficiently high to suggest that phytoplankton growth is light limited in the Snake River. Nutrient levels in the mid-Columbia River are sufficiently low to suggest that both light and nutrients may be limiting factors. The computed phytoplankton concentrations are shown in Figure H–9. Within the model, the limiting effect of light on phytoplankton growth is a direct function of self shading, the light attenuation characteristics assigned to the water and the light intensity at which algae growth at 1/2 their maximum rate (light saturation constant).

In the context of the one dimensional vertically averaged model (longitudinally segmented reservoir and stream model), the light half saturation constant should attempt to compensate for intermittent light effects associated with vertical mixing and for vertical variations in the weakly stratified reservoirs. Selecting a representative half saturation constant is difficult without observed phytoplankton levels. Therefore, the results presented in Figure H–9 reflect a general understanding of background phytoplankton levels.

The effects of the model representation of reservoirs can be seen in Figure H–9. Growth of phytoplankton is computed in the upper end of Lake Roosevelt. As the depth increases downstream, the limiting effect of nutrients and light halt the rise in the algae concentration near mile 690. The Snake River plot shows a low algae concentration in the Brownlee release (mile 610) with a general raise in concentration to the upstream end of Lower Granite and a more rapid increase in Lower Granite. The low concentration in Brownlee is due to the release of near bottom water which is low in algae due to the absence of light. The general raise in the river above Lower Granite is due to the availability of light but the short residence time limits the rate of growth. The more rapid increase in Lower granite reflects the lower flow velocity and increased residence time.

## H–6 pH

The pH is controlled by the relationship between alkalinity and components of inorganic carbon (IC). Chemical equilibrium relationships between the components of IC (carbonate, bicarbonate and carbon dioxide) are utilized in the determination of pH. Sources of CO include exchange at the water surface and by products of algal respiration and carbonaceous decay. Sinks of $CO_2$ in the water column include exchange at the water surface with the atmosphere and uptake associated with algal growth.

The computed pH profiles are shown in Figure H–10. These results show that the model over-predicts pH, particularly in the more downstream reaches. High pH values are typically associated with low TIC levels relative to carbonate alkalinity and are often result of excessive loss of $CO_2$. This shortcoming can likely be eliminated by modifying the relationships controlling surface exchange of $CO_2$ and will be resolved prior to delivery of the final model and report.

## H–7 SUSPENDED SEDIMENT

The model contains the option to simulate up to three particle sizes and may be either organic or inorganic. From a practical perspective there is not sufficient data available to subdivide the suspended solids into more than one particle size. The available suspended sediment data is limited to the total suspended solids concentration and the percent passing a .062 mm screen. The percent passage data indicates the majority of the suspended sediment load within the river system represented by the mode is composed by very fine particles. Also, all but the smallest particles are almost immediately lost in the slow moving water of the many reservoirs within the system. The finest particles are also the most important from a turbidity and from a pollutant transport perspective, since the extent to which pollutants are sorbed on particulate is correlated with particle surface area.

Inorganic suspended sediments are lost through deposition and resuspension and are replenished by point and non-point sources. The observed data suggest that the suspended sediment concentration remains fairly constant in the Columbia River and is increased from sources in the Snake River (as is the case with almost all parameters). It appears that any loss due to settling is compensated for by ill defined non-point sources. The model results shown in Figure H–11 reflect a settling rate of 0.5 and 0.1 meters/day settling rate for the reservoirs and streams, respectively. The lower net effective settling rate in the stream section is due to added turbulence associated with higher velocities. Non-point source rates (which could represent irrigation returns, dust settling on the water surface, and shoreline erosion) of up to two tones/day/mile are required to counter the effects of settling rates of this magnitude. The combinations of settling rates and non-point source rates could result in good replication of observed suspended sediment concentration. The ramification of the tradeoff between these two inputs are significant from the perspective of pollutant transport. Loss of sorbed pollutants associated with deposition versus the rate of gain associated with the non-point source can have significant effect on pollutant concentration. This effect is discussed in more detail in the following section.

## H–8 TOXIC POLLUTANTS

Toxic pollutants include heavy metals, radionuclides, dioxins and furans and other dissolved organic chemicals. The processes effecting the concentration of each of these pollutants are somewhat similar. All of these parameters have a tendency to adhere to solids both in the water column and in the bottom. The organic chemicals (including dioxins and furans) tend to be fairly insoluble in water and have an affinity to organic material. Therefore, the organic films on the particulate and within the bottom sediments effect the sorption rates. The low solubility also creates the driving force required for volatilization. Decay is also significant for many organic chemicals and distinguishes radionuclides from normal heavy metals. Precipitation of metals is possible when concentrated effluents are discharged to some receiving waters. Since the modeling effort is centered around major tributary discharges, concentration sufficiently high for precipitation of metals is very unlikely and therefore, is not considered. (The EPA (1985) reports that lead and zinc are 100% dissolved for concentrations of 100 and 200 ug/l respectively in the Columbia River.) Each pollutant is modeled as the total (sorbed + dissolved). The input data are for the dissolved fraction, therefore the values for the total pollutant are a function of the partitioning coefficients.

### H–8.1 Heavy Metals and Radionuclides

Sources and sinks of heavy metals would include reversible exchange with suspended organic and inorganic particulate and phytoplankton and exchange with bottom sediments through pore water diffusion. The concentration in the pore water is computed as a function of the total metal content of the bed. Decay is included for simulating radionuclides.

Lead and Zinc were the two metals selected to demonstrate the utility of the model. Both of these metals are found at sufficiently high concentrations as to provide adequate data for defining inflows and for rough calibration. The computed concentration of dissolved lead and zinc are shown on Figures H–12 and H–13. These results show a trend of decreasing concentration as the flow progresses downstream. The range in observed concentration is such that it is difficult to assesses the accuracy of the model however lower concentration are generally observed as the flow progresses downstream.

It is important to evaluate the relationship between dissolved and total metals since total metals concentration is often used in water quality criteria. Figure H–14 shows the computed total and dissolved fraction of zinc. The total zinc is a function of the suspended solids concentration shown in Figure H–11, a partitioning constant determined from the statistical summary data at Warrendale and Northport and the suspended solids exponent of 0.32 (EPA, 1985). These results predict that total zinc exceeds the dissolved fraction by a large factor. The concentration of total zinc is very sensitivity to the partitioning coefficient in the context of the model formulation (it is determined as a function of dissolved zinc). Figure H–15 shows the effects of halving the partitioning coefficient on the total zinc concentration. The dissolved fraction is changed only slightly by having the partitioning coefficient.

Because of the uncertainty in the metals calibration, it is important to examine the sensitivity to various input parameters. Figure H–16 shows the effect of bottom exchange on the dissolved zinc concentration in the Columbia River. The top half of the figure shows the effects of the bottom diffusion rate being increased by a factor of ten and the bottom half shows the effect of increasing the sediment pore water concentration of two. These results show that the concentration of dissolved zinc is fairly insensitive to bottom exchange parameters. This insensitivity is not surprising due to the large average depth (approximately 60 feet) of the Columbia River system encompassed by the model. At a depth of 60 feet, a 1mg/m2/day flux rate would result in a total metal concentration increment of only 0.05 ug/l/day in the water column. The insensitivity to bottom exchange means that the sorption - desorption relationships in the water column, and the resulting loss through particulate settling, is the only important internal model processes controlling metals (and other pollutants) concentrations.

Figures H–12 through H–16 are provided for reference purposes only, as observation data are questionable.

### H–8.2 Dioxins and Furnas and other Dissolved Chemicals

Sources and sinks of dioxins and furans and other dissolved chemicals include reversible exchange with suspended organic and inorganic particulate and phytoplankton and exchange with bottom sediments through pore water diffusion. Loss through volatilization and decay is also significant for some of these parameters. The insensitivity to bottom exchange described above also holds true for these parameters. Volatilization is also a function of the ratio of area to depth, therefore volatilization is only significant for the most volatile materials.

The lack of water column data restrict the options for model calibration. Most attempts at monitoring these parameters results in non detects. Therefore the modeling approach is limited to defining model coefficients based on available laboratory data and accepting the model results subject to the absence of model calibration. Partitioning coefficients may be estimated based on the octanol-water partitioning coefficients and by assuming the organic component of suspended particulate and bottom sediment (approximately 1% and 0.3% respectively). The volatilization rate may be estimated based on the Henry's Law constant.

The results presented on Figures H–17 and H–18 show the computed concentrations of dioxin and DDE pesticide residuals respectively. The magnitude of the concentrations is completely arbituary with the point and non-point inputs reflecting my understanding of the land uses and industrial discharges. The dioxin tracer inputs assume elevated concentrations in the inflow to Lake Roosevelt from the

## Table H–1. Ranges of Observed Concentrations During the Summer Month of Selected Water Quality Parameters in the Stream and Reservoirs of the Columbia - Snake River System

| Site | Flow | Temp | pH | Alk | S04-- | CL- | TDS | NO3 | NH3 | TKN | PO4 | TOC | DOC | S.Sed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Columbia R. @ Northport | | | | | | | | | | | | | | |
| 6-78 | 70-140 | 12-18 | 7.6-7.9 | 48-62 | 9-19 | 1-2 | 73 | .05 | .02 | .1-.2 | .05 | 1-3 | 3.7 | 3-6 |
| 7-79 | 60-117 | 12-19 | 7.6.-8.1 | 41-50 | 13-16 | .6-1 | 77 | .10 | .05 | .2-.4 | .03 | 1-3 | 2.4 | 4-8 |
| 2-80 | 86-126 | 11-19 | 7.8-8.0 | 50-53 | 9-15 | .6-1 | 77 | .04 | .05 | .4-1.7 | .03 | 4.3 | 2-4 | 7-9 |
| 3-84 | 88-93 | 16-17 | 7.8-7.9 | 52-54 | 11-12 | .6-1 | 73 | <.1 | .03 | .2-.4 | .04 | | | 2-12 |
| 4-85 | 61-88 | 15-19 | 8.0-8.1 | 51-66 | 10 | .7-1 | 70 | <.1 | .06 | .2-.3 | .015 | | | 2-4 |
| 5-86 | 98-113 | 16-18 | 8.1 | 51 | 9 | .6-.8 | 78 | <.1 | .02 | .2-.3 | <.01 | | | 2-4 |
| 9-90 | 67-117 | 16-19 | 7.9-8.1 | 50-50 | 7-12 | .5-1. | 67 | <.1 | .02 | .2-.3 | .015 | | | 1-4 |
| Columbia R. @ Vernita Br. | | | | | | | | | | | | | | |
| 3-84 | 48-175 | 11-18 | 7.5-7.9 | 50-57 | 9-12 | 1-1.7 | 85 | .1 | .03 | .2.6 | .01 | | | 3-6 |
| 4-85 | 55-114 | 11-20 | 7.6-8.2 | 55-63 | 9-11 | 1-1.3 | 74 | <.1 | .04 | .2-.4 | .02 | | | 2-4 |
| 5-86 | 66-145 | 12-18 | 8.1-8.4 | 54-65 | 10-13 | .9-2 | 75 | .1 | .03 | .2-.3 | .01 | | | 3-7 |
| 9-90 | 52-178 | 14-20 | 8.1-8.2 | 55-63 | 6-11 | .4-2 | 72 | <.1 | .01 | <.2 | .015 | | | 1-6 |
| Columbia R. Below Bonneville | | | | | | | | | | | | | | |
| 5-86 | 134-156 | 12-21 | 7.8-7.9 | 61-76 | 10-16 | 2-4 | 105 | .02 | .02 | .2-.3 | .02 | | | 9-10 |
| Snake R. @ Weiser. | | | | | | | | | | | | | | |
| 3-84 | 15-21 | 14-26 | 8.6-8.7 | 138-158 | 50 | 13-19 | 275 | .4-1.1 | .07 | .7-.9 | .03 | | | 86-117 |
| 4-85 | 10-24 | 18-26 | 8.6-8.9 | 121-178 | 39-62 | 14-21 | 315 | .7-1.2 | .045 | .8-1.3 | .04 | | | 37-94 |
| 9-90 | 8-18 | 13-26 | 8.8-8.9 | 112-173 | 30-58 | 14-25 | 318 | .9 | .025 | .3-2.1 | .01 | | | 72-102 |
| Snake R. @ Burbank | | | | | | | | | | | | | | |
| 3-84 | 25-81 | 10-23 | 7.6-7.7 | 59-126 | 13-33 | 5-12 | 150 | .1-.8 | .06 | .3 | .03 | | | 6-10 |
| 4-85 | 25-34 | 9-22 | 7.5-7.8 | 74-122 | 20-33 | 8-15 | 150 | .1-.8 | .05 | .3 | .03 | | | 3-6 |
| 5-86 | 16-33 | 10-21 | 7.9-8.2 | 68-113 | 16-25 | 6-11 | 150 | .1-.7 | .06 | .4 | .04 | | | 6-7 |
| 9-90 | 25-38 | 14-23 | 7.8-8.0 | 46-100 | 10-24 | 5-10 | 125 | .1-.4 | .02 | .2 | .02 | | | 6 |
| Snake River @ Hells Canyon | | | | | | | | | | | | | | |
| 4-85 | 18 | 18 | 8.4 | 163 | 57 | 18 | 275 | .9 | .04 | .5 | .07 | | | |
| 3-84 | 30 | 19 | 8.1 | 150 | 50 | 15 | 288 | 1.1 | .05 | .5 | .1 | | | |
| Salmon River @ White Bird | | | | | | | | | | | | | | |
| 3-84 | 6-14 | 11-18 | 8.0-8.5 | 49-76 | 8-12 | 1-3 | 95 | <.1 | .035 | .2 | .015 | | | 6-9 |
| 4-85 | 5-6 | 13-22 | 8.5-8.6 | 66-75 | 10-15 | 2-3 | 100 | <.1 | .035 | .4-.5 | .02 | | | 3-5 |

## Table H–1. Ranges of Observed Concentrations During the Summer Month of Selected Water Quality Parameters in the Stream and Reservoirs of the Columbia - Snake River System – CONT

| Site | Flow | Temp | pH | Alk | S04-- | CL- | TDS | NO3 | NH3 | TKN | PO4 | TOC | DOC | S.Sed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9-90 | 3-7 | 13-26 | 8.2-8.6 | 51-72 | 6-10 | 2-3 | 75 | <.1 | <.01 | .2-.3 | <.01 | | | 2-3 |
| Clearwater R. @ Spalding | | | | | | | | | | | | | | |
| 3-84 | 7-13 | 11-21 | 7.9-8.1 | 14 | 2.3 | .5 | 29 | <.1 | .o5 | .3 | <.01 | | | 2-3 |
| 4-85 | 4-5 | 12-19 | 6.5-7.3 | 21-43 | 3 | .7 | 28 | <.1 | .035 | .2 | <.01 | | | 3-5 |
| 7Sep85 | 5 | 12 | 6.5 | 43 | 2.8 | 1. | 29 | | | | | | | 5 |
| 9-90 | 5-11 | 13-20 | 7.7-7.9 | 15-16 | <1 | .5 | 28 | <.1 | .02 | .<.2 | <.01 | | | 2 |
| Spokane R @ Long Lake | | | | | | | | | | | | | | |
| 11 | 3-5 | 18-19 | 7.8-8.1 | 47-87 | 8-14 | 2-3 | 100 | .5 | .05 | .35 | .015 | | | 2-5 |
| Yakima River @ Kiona | | | | | | | | | | | | | | |
| 8-80 | | | | | | | | | | | | 2-4 | | |
| 3-84 | 3 | 15 | 7.4-7.9 | 42-54 | 4-6 | 2.6 | 90 | .15 | .025 | .3 | .03 | | | 36-42 |
| 4-85 | 3 | 14-19 | 7.4-8.2 | 54-60 | 4-7 | 2.7 | 70 | .32 | .05 | .35 | .05 | | | 11-33 |
| 9-90 | 3 | 8-16 | 8.0-8.2 | 40-64 | 2-6 | 2.7 | 54 | .1 | .03 | .45 | 03 | | | 19-32 |
| Deschutes R. @ Moody | | | | | | | | | | | | | | |
| 3-84 | 5-5 | 17-19 | 8.3-8.6 | 61-62 | 3.8 | 2.0 | 92 | <.1 | .025 | .3 | .13 | | | 4-15 |
| 4-85 | 4-5 | 13-18 | 7.8-8.0 | 64-67 | 3.7 | 3.2 | 88 | <.1 | .055 | .3 | .06 | | | 9-12 |
| 5-86 | 5 | 15-18 | 7.9-8.1 | 59-60 | 2-4 | 2.2 | 90 | <.1 | .03 | .3 | .04 | | | 2-4 |
| 9-90 | 4-5 | 16-22 | 8.1-8.2 | 57-59 | 1.9 | 2.8 | 95 | <.1 | .015 | .2 | .04 | | | 8-11 |
| Skanogan River at Mallot | | | | | | | | | | | | | | |
| 11 | .5-3 | 22-26 | 8.2-8.5 | 92-132 | 26-38 | 2-3 | 160 | .1 | .01 | .35 | <.01 | | | 2-15 |
| Klicitat R. near Pitt | | | | | | | | | | | | | | |
| 11 | 1 | 14-18 | 7.7-8.3 | 35-45 | 2-3 | 1.1 | 70 | <.1 | .04 | .5 | .025 | | | 4-7 |
| John Day R. @ McDonald Ferry | | | | | | | | | | | | | | |
| 11 | .1-.6 | 14-24 | 8.5-8.9 | 126-158 | 10-16 | 3.6 | 150 | <.1 | .04 | .4 | .025 | | | 1-4 |

Source: Yearly USGS Water Quality Data Reports

## Table H–2. Concentration of Point and Non–Point Inflow

| Tributary | Temp .C | TDS mg/l | N03 mg/l | P04 mg/l | Algae mg/l | CBOD mg/l | NH3 mg/l | Oxy mg/l | Cl– mg/l | Alka mg/l | pH units | DDE ug/l | Lead ug/l | Zinc ug/l | Diox ug/l | SS#1 mg/l | SS#2 mg/l | Col. MPN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| #1 – Dworshak Inflow | 14.5 | 30. | .03 | .01 | .3 | .5 | .02 | 9.0 | .7 | 18. | 7.7 | .1 | 1. | 3. | .1 | 4. | .3 | 100. |
| #2 – Brownlee Inflow | 18. | 300. | 1.0 | .03 | 2. | 2. | .04 | 8.0 | 17. | 150. | 8.5 | 2. | 2. | 8. | .1 | 60. | 2. | 500. |
| #3 – Salmon / G.R.R. | 16. | 85. | .05 | .01 | .5 | 1. | .03 | 8.5 | 2.5 | 65. | 8.3 | 0.2 | 2. | 5. | 0.1 | 5. | .5 | 100. |
| #4 – Clearwater R. | 16. | 30. | .03 | .01 | .3 | .5 | .02 | 9.0 | .7 | 18. | 7.7 | 0.2 | 2. | 5. | 0.1 | 4. | .3 | 100. |
| #5 – Palouse R. | 17. | 75. | .15 | .03 | 1. | 1. | .04 | 8.0 | 2.5 | 55. | 8.0 | .5 | 2. | 5. | .1 | 15. | 1. | 300. |
| #6 – Grand Coulee Inflow | 14. | 70. | .04 | .02 | .8 | 1. | .03 | 8.8 | .8 | 52. | 7.9 | .2 | 4. | 12. | .5 | 4. | .8 | 100. |
| #7 – Upper Columbia Trib. | 16. | 75. | .10 | .03 | 1.. | 1. | .04 | 8.0 | 2.5 | 55. | 8.0 | 1. | 2. | 4. | .1 | 8. | 1. | 300. |
| #8 – Yakima R. | 17. | 75. | .15 | .03 | 1. | 1. | .04 | 8.0 | 2.6 | 65. | 7.9 | .5 | 1. | 4. | .1 | 32. | 1. | 300. |
| #9 – John Day R. | 16. | 150. | .05 | .03 | 1. | 1. | .04 | 8.0 | .5 | 140. | 8.7 | .5 | 1. | 6. | .1 | 4. | 1. | 300. |
| #10 – Deschytes R | 16. | 90. | .05 | .05 | 1. | 1. | .03 | 8.0 | 2.5 | 60. | 8.0 | .5 | 1. | 6. | .1 | 8. | 1. | 300. |
| #11 – Klickitat R. | 16. | 70. | .05 | .03 | 1. | 1. | .04 | 8.0 | 1.5 | 40. | 8.0 | .5 | 2. | 5. | .1 | 5. | 1. | 300. |
| #12 – Pulp Kill Mass | 33. | 500. | 1. | .3 | 0. | 50. | 2. | 4.0 | 50. | 100. | 9.0 | 10. | 3. | 9. | 10000 | 50. | 0. | 1000. |
| #13 – Non Point Loading | 18. | 175. | .50 | .15 | 1. | 3. | .15 | 8.0 | 5.0 | 55. | 7.9 | .5 | 2. | 10. | .0 | 50. | 1. | 500. |

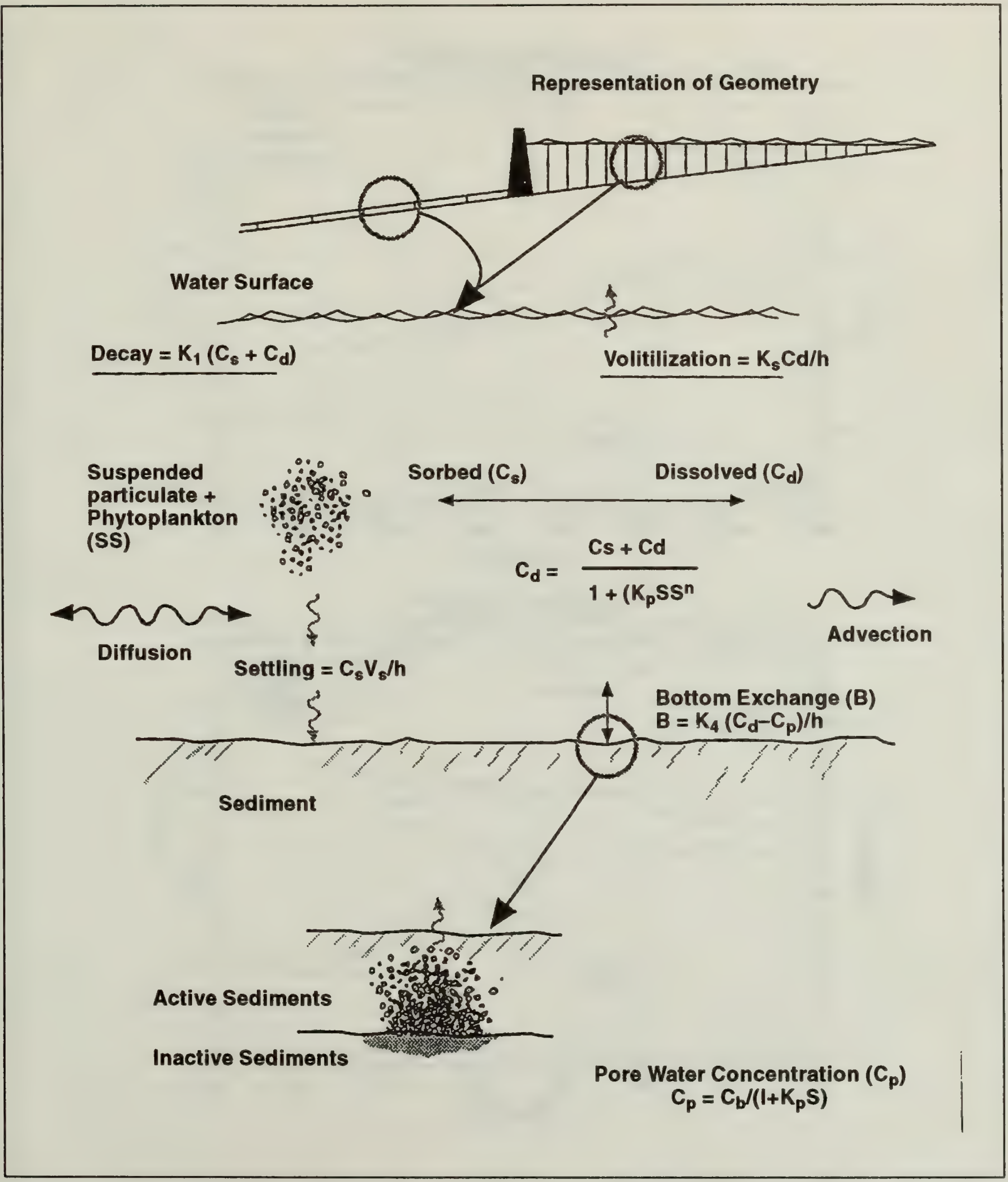


**Figure H–1. Processes Controling Pollutant Kinetics as Represented by HEC5Q**

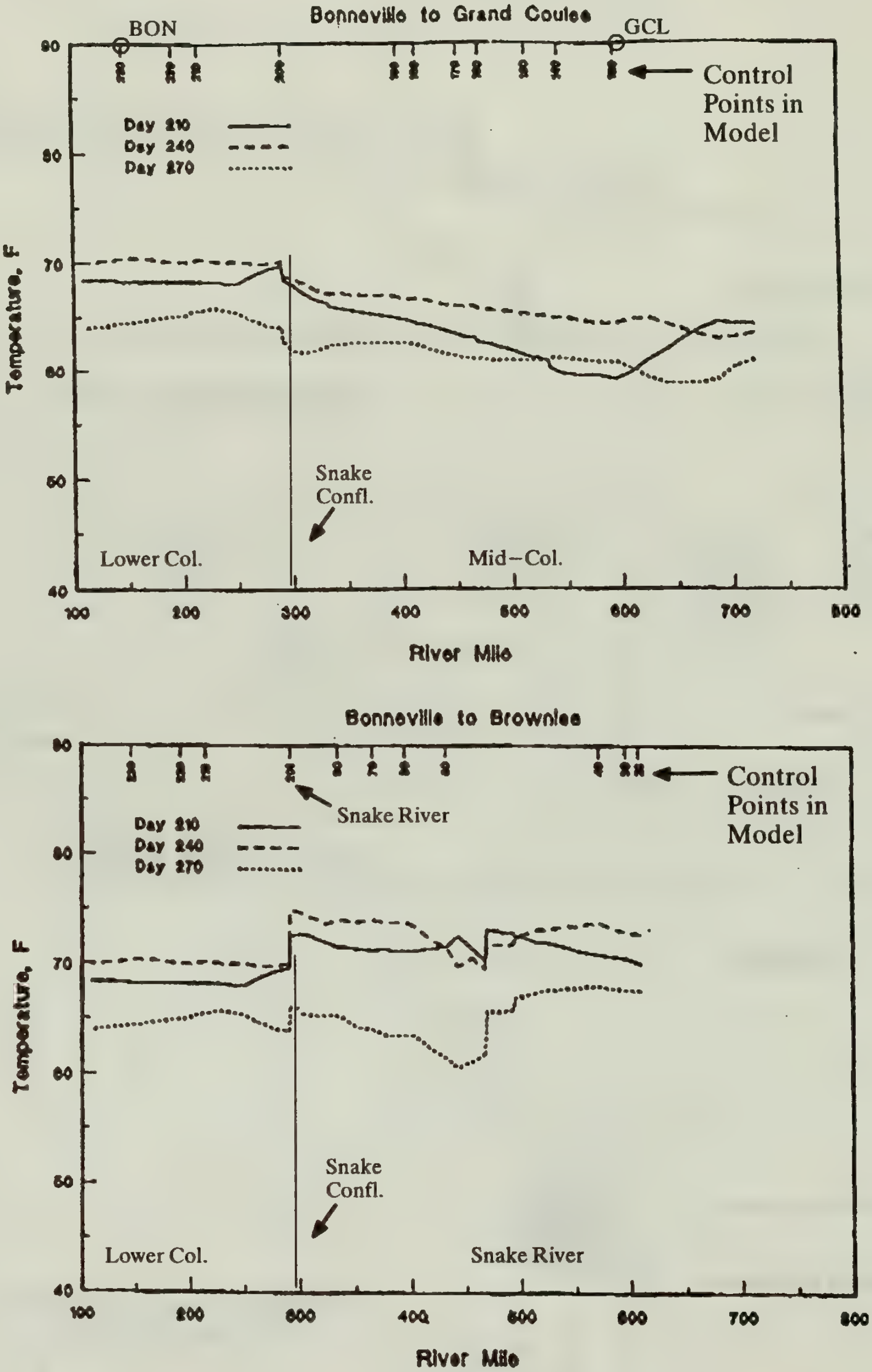


Figure H–2. **Computed Temperature Profiles in the Columbia and Snake River System Near the End of July, August, and September**

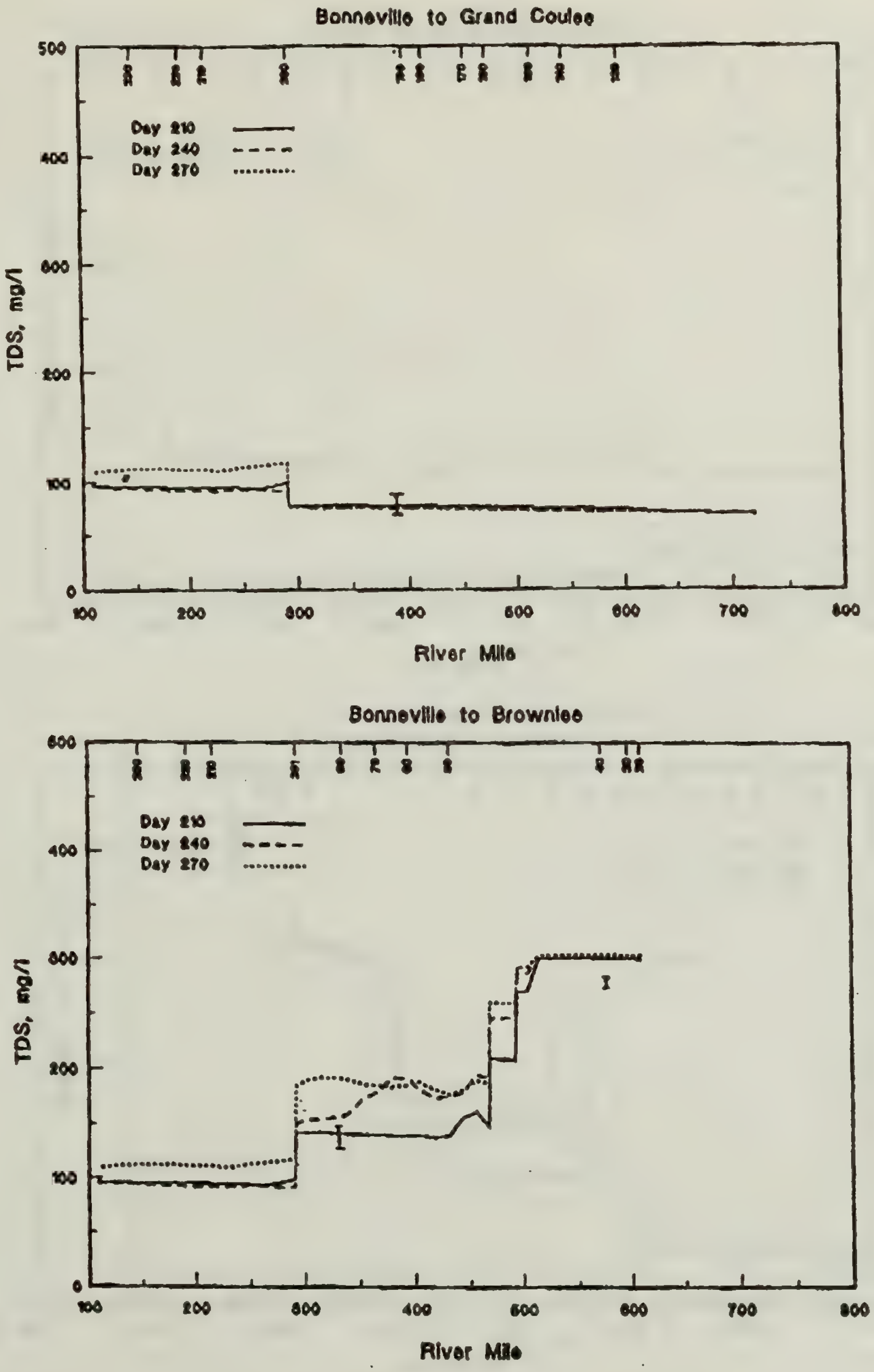


**Figure H–3. Computed TDS Profiles in the Columbia and Snake River System Near the End of July, August, and September**

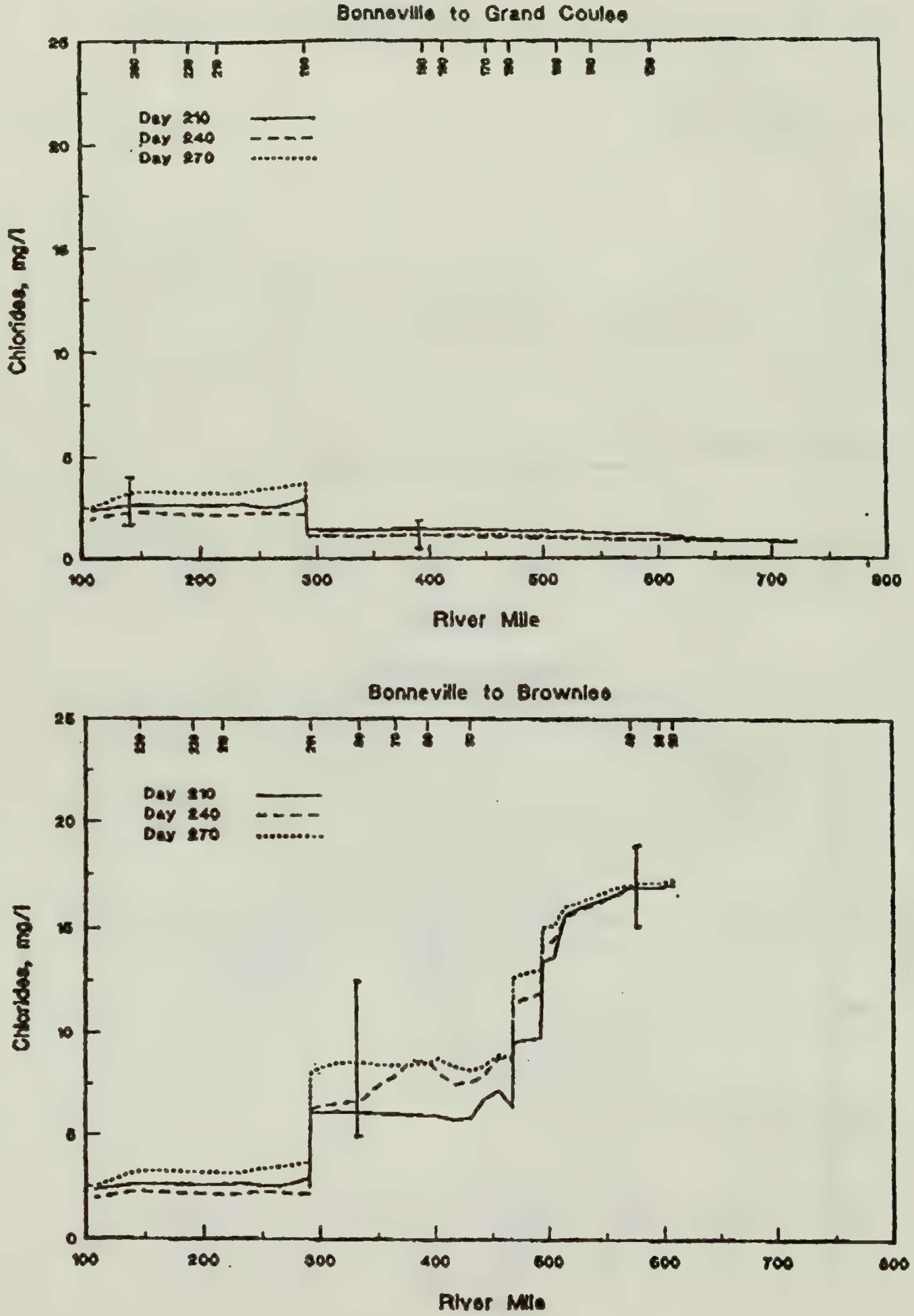


**Figure H–4. Computed Chloride Profiles in the Columbia and Snake River System Near the End of July, August, and September**

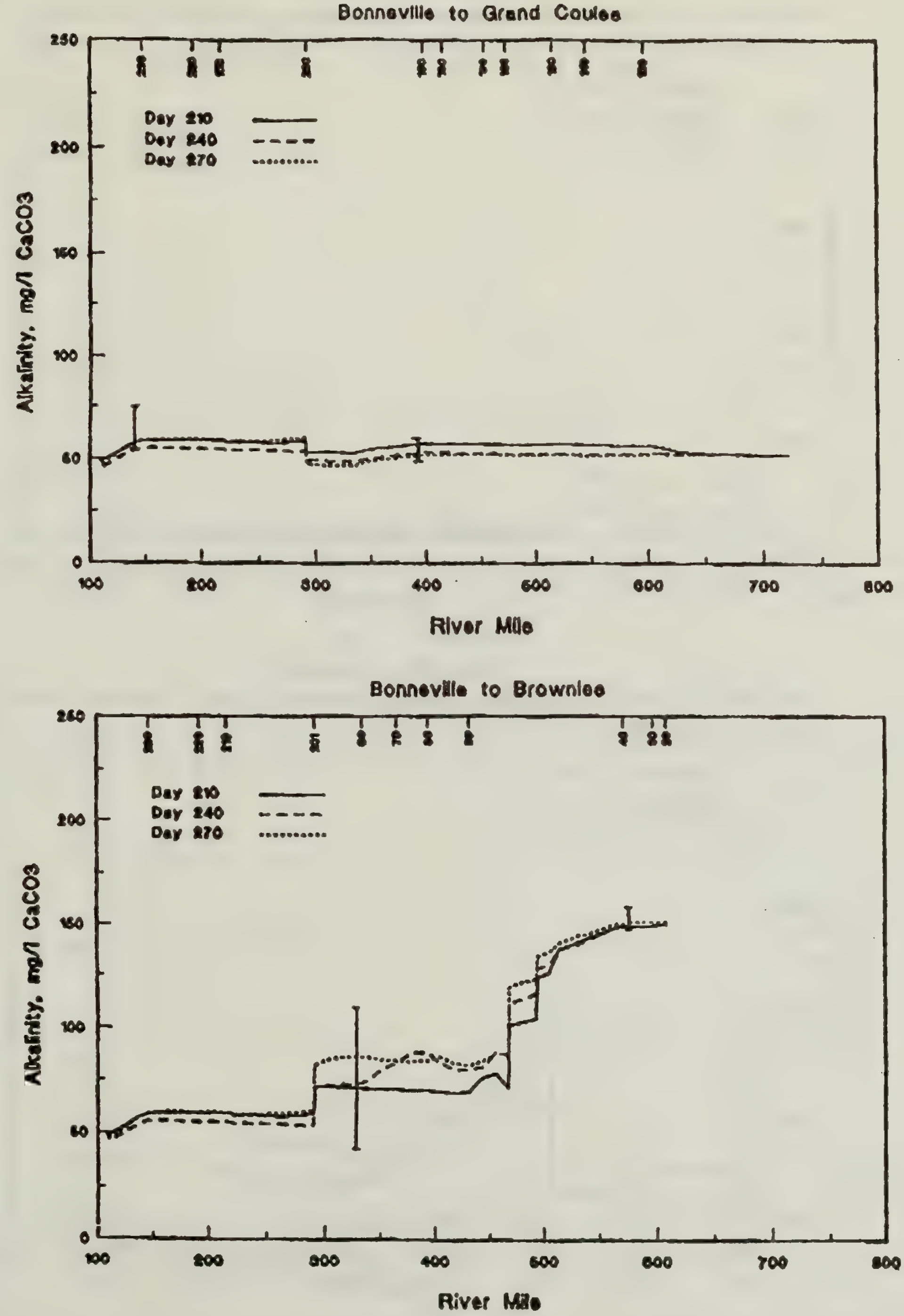


**Figure H–5. Computed Alkalinity Profiles in the Columbia and Snake River System Near the End of July, August, and September**

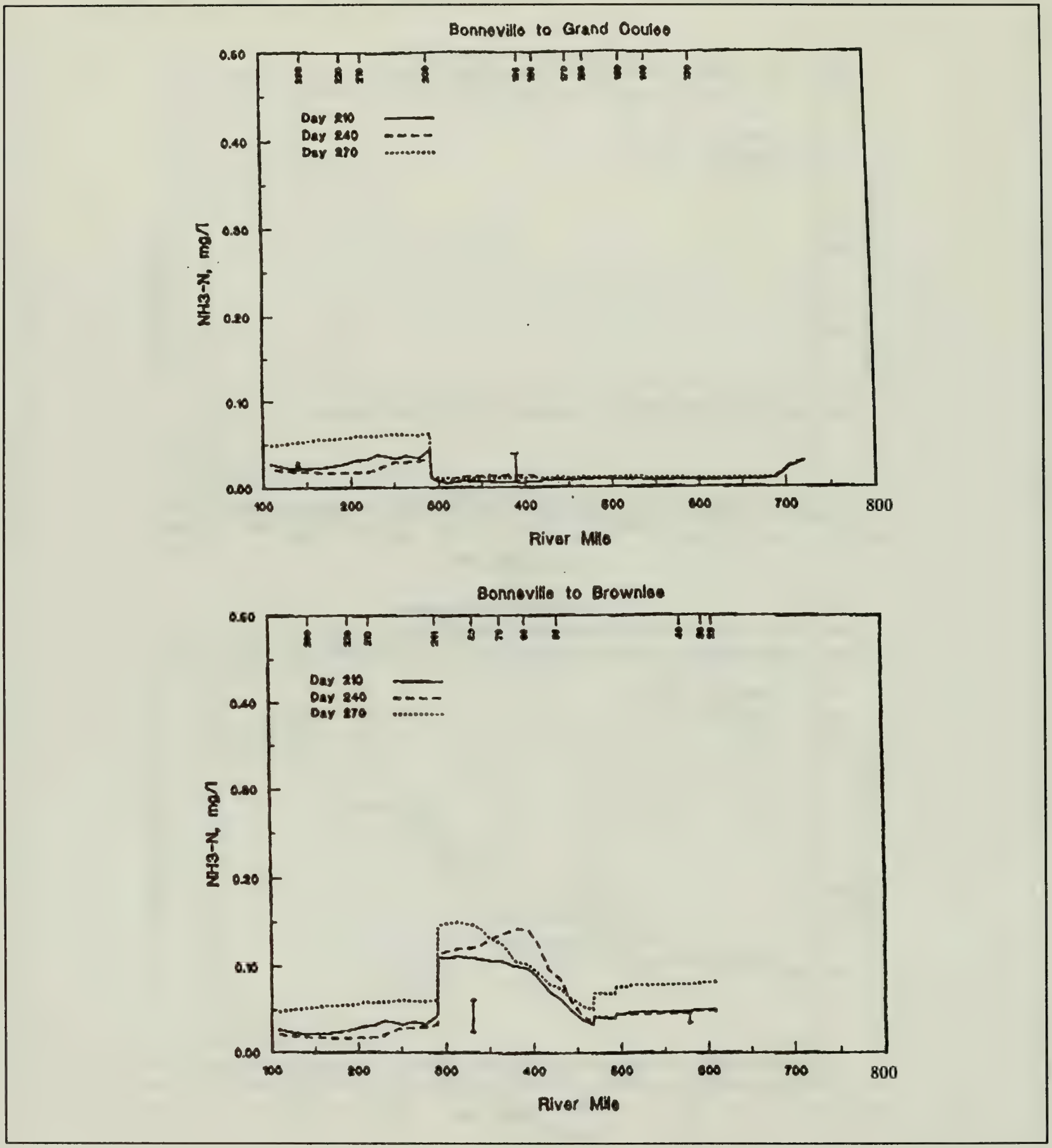


**Figure H–6. Computed Ammonia Nitrogen Profiles in the Columbia and Snake River System Near the End of July, August, and September**

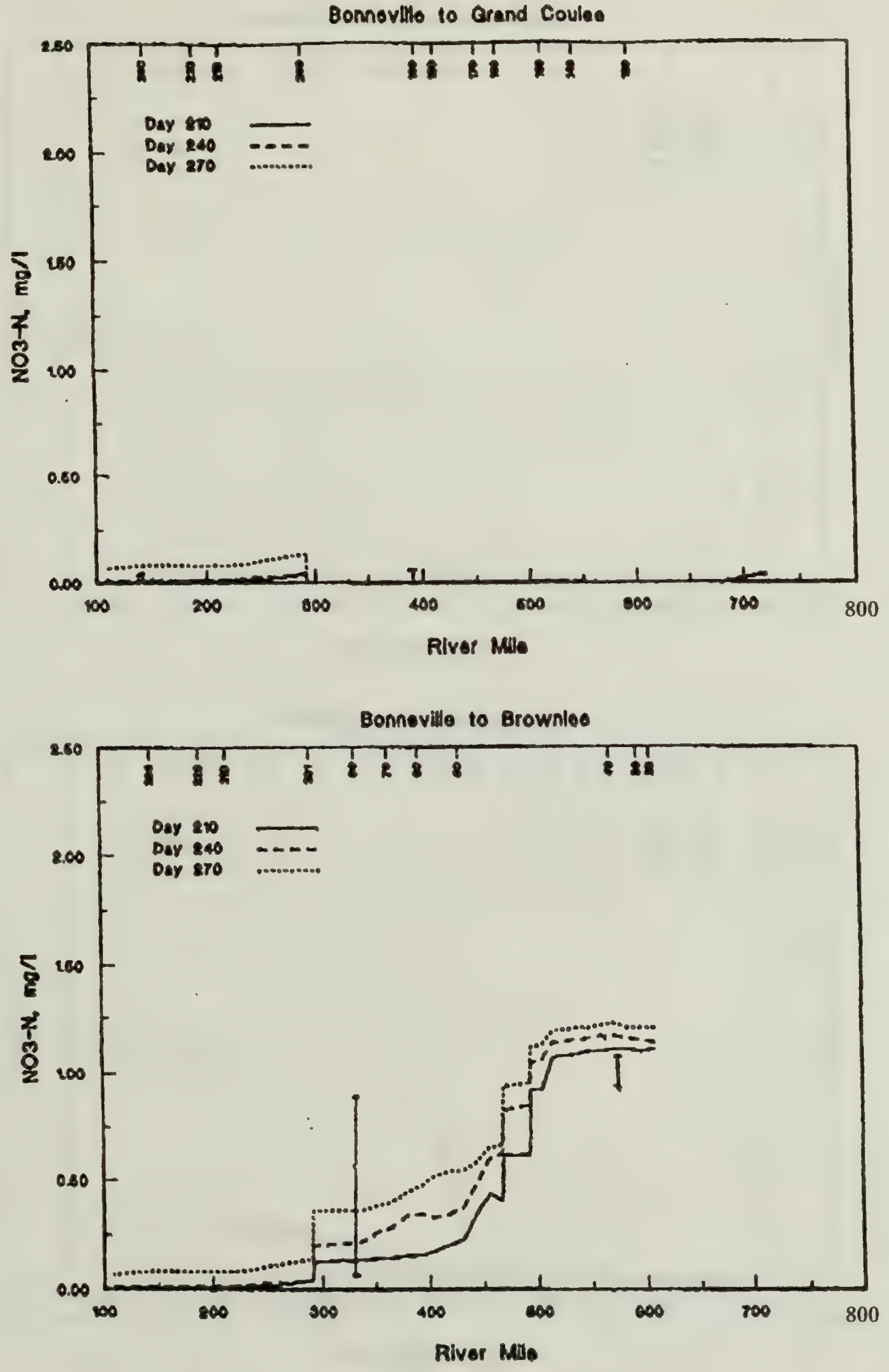


**Figure H–7. Computed Nitrate Nitrogen Profiles in the Columbia and Snake River System Near the End of July, August, and September**

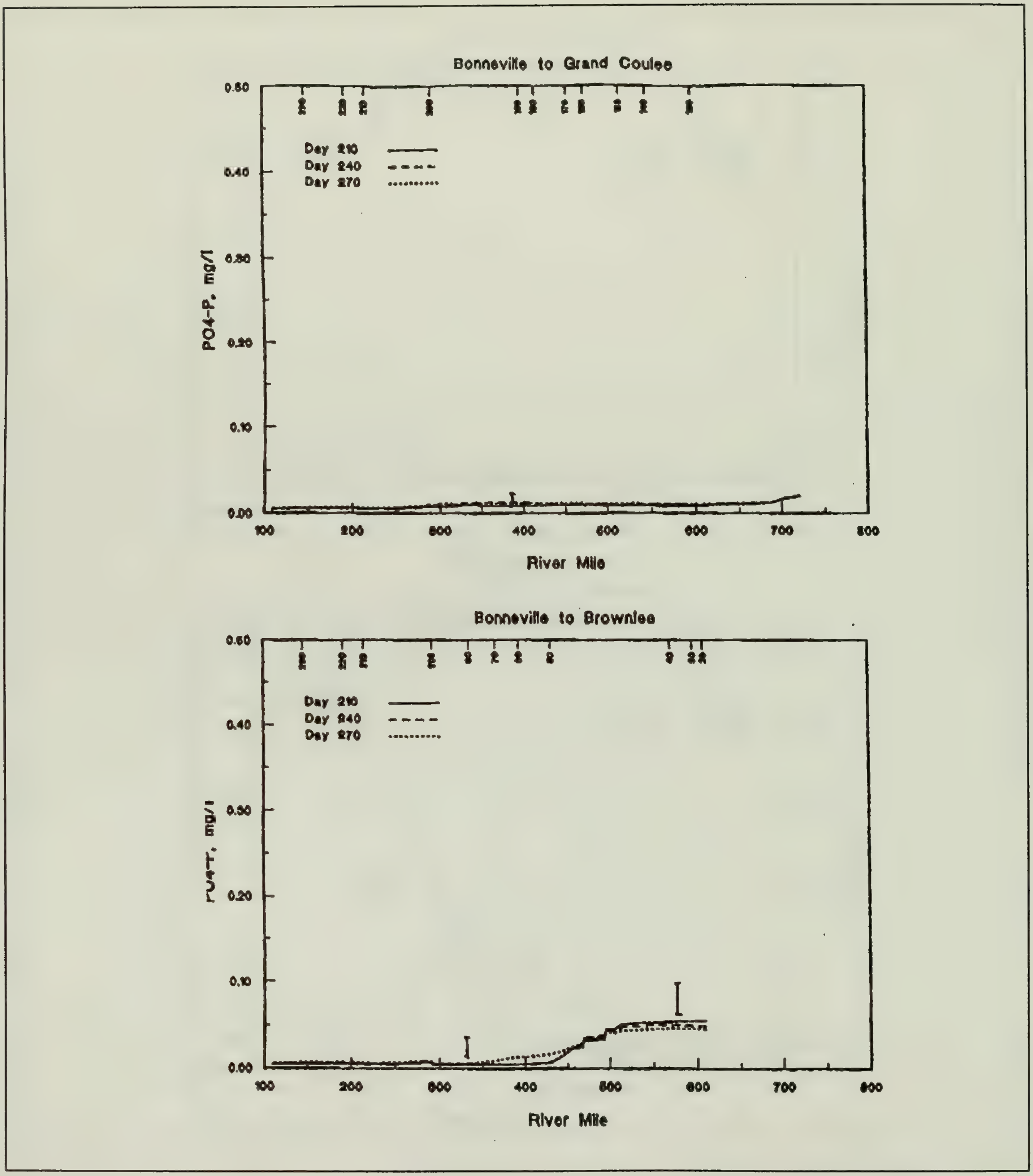


**Figure H–8.** **Computed Phosphorus Profiles Profiles in the Columbia and Snake River System Near the End of July, August, and September**

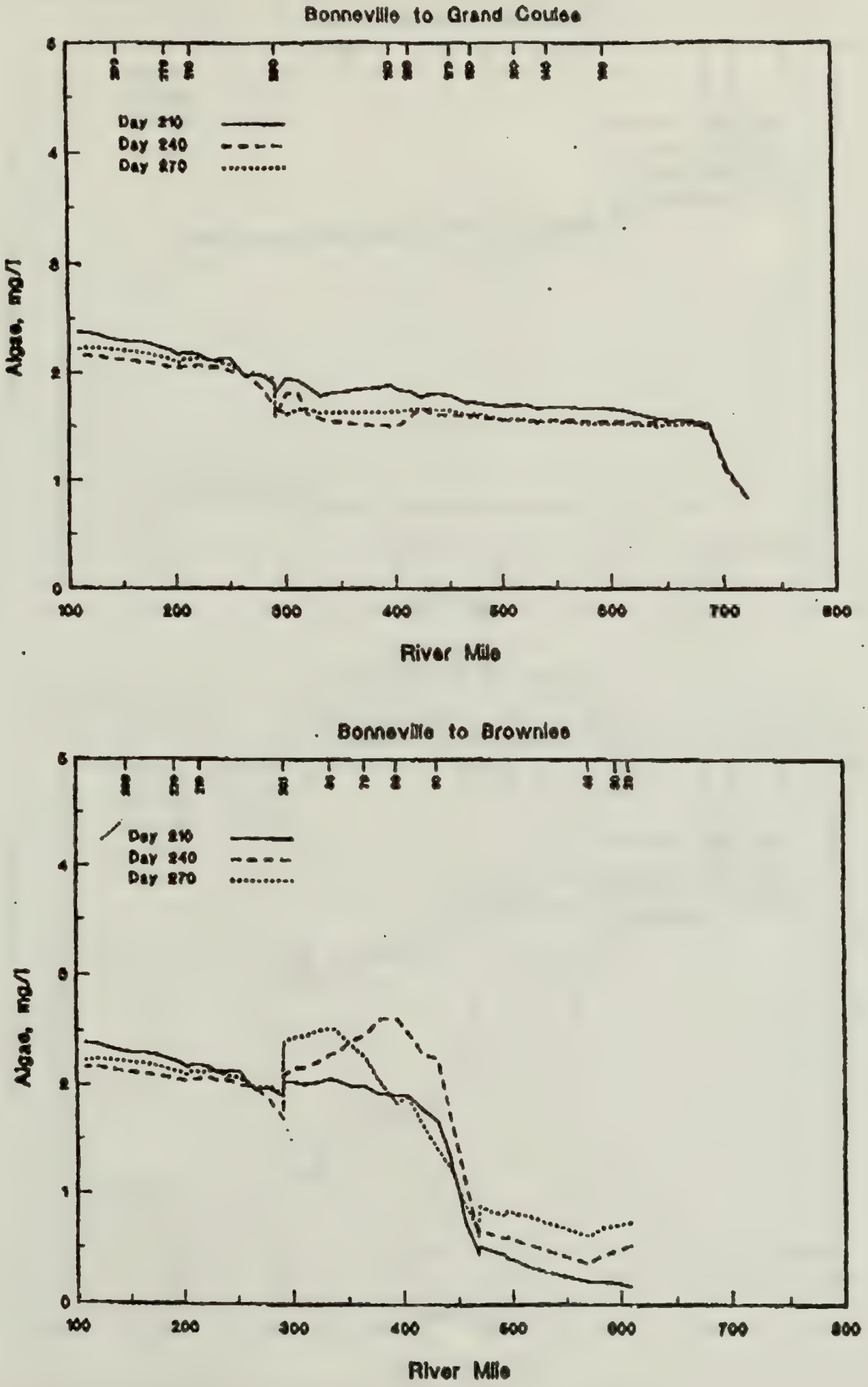


Figure H–9. Computed Phytoplankton Profiles in the Columbia and Snake River System Near the End of July, August, and September

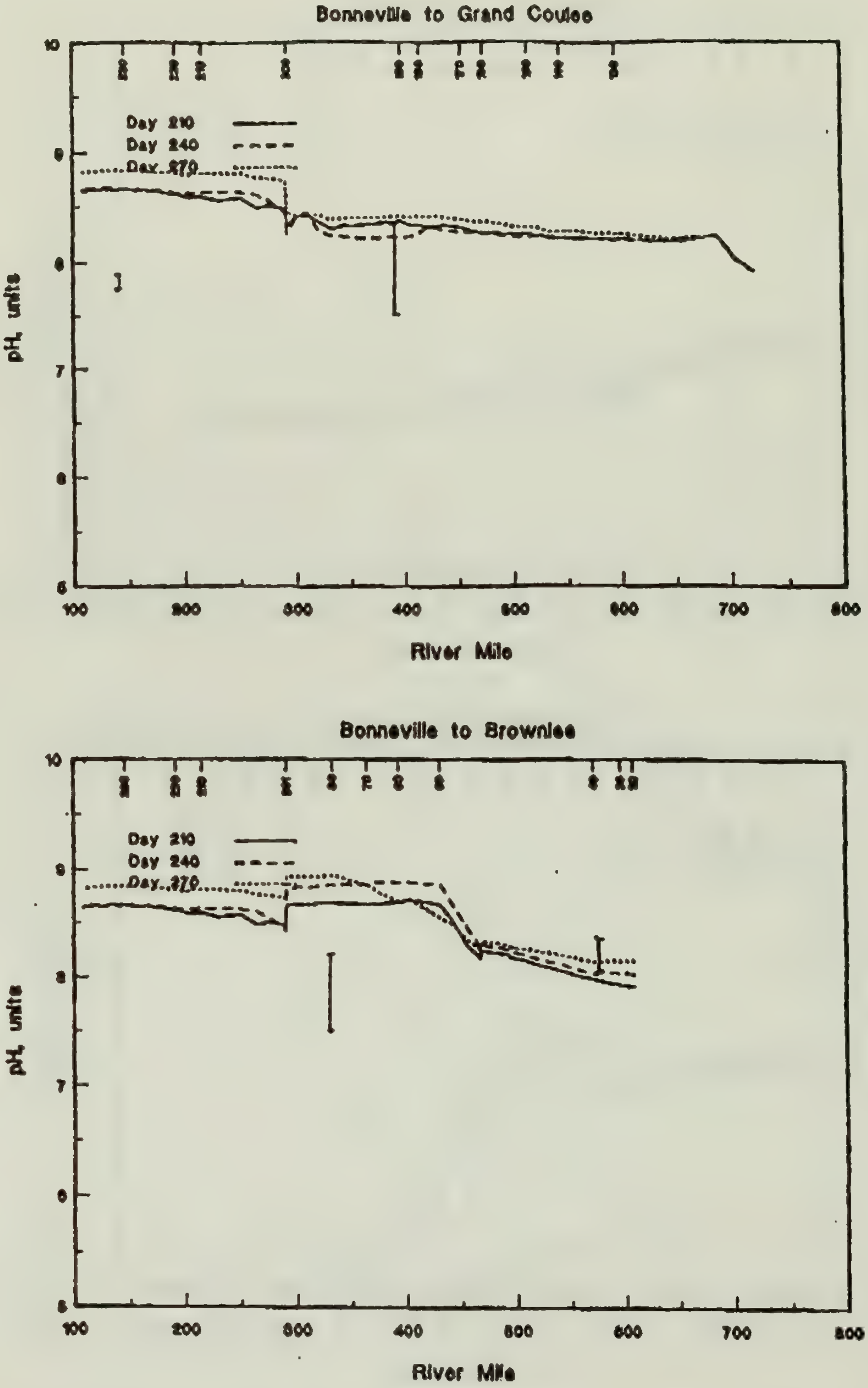


**Figure H–10. Computed pH Profiles in the Columbia and Snake River System Near the End of July, August, and September**

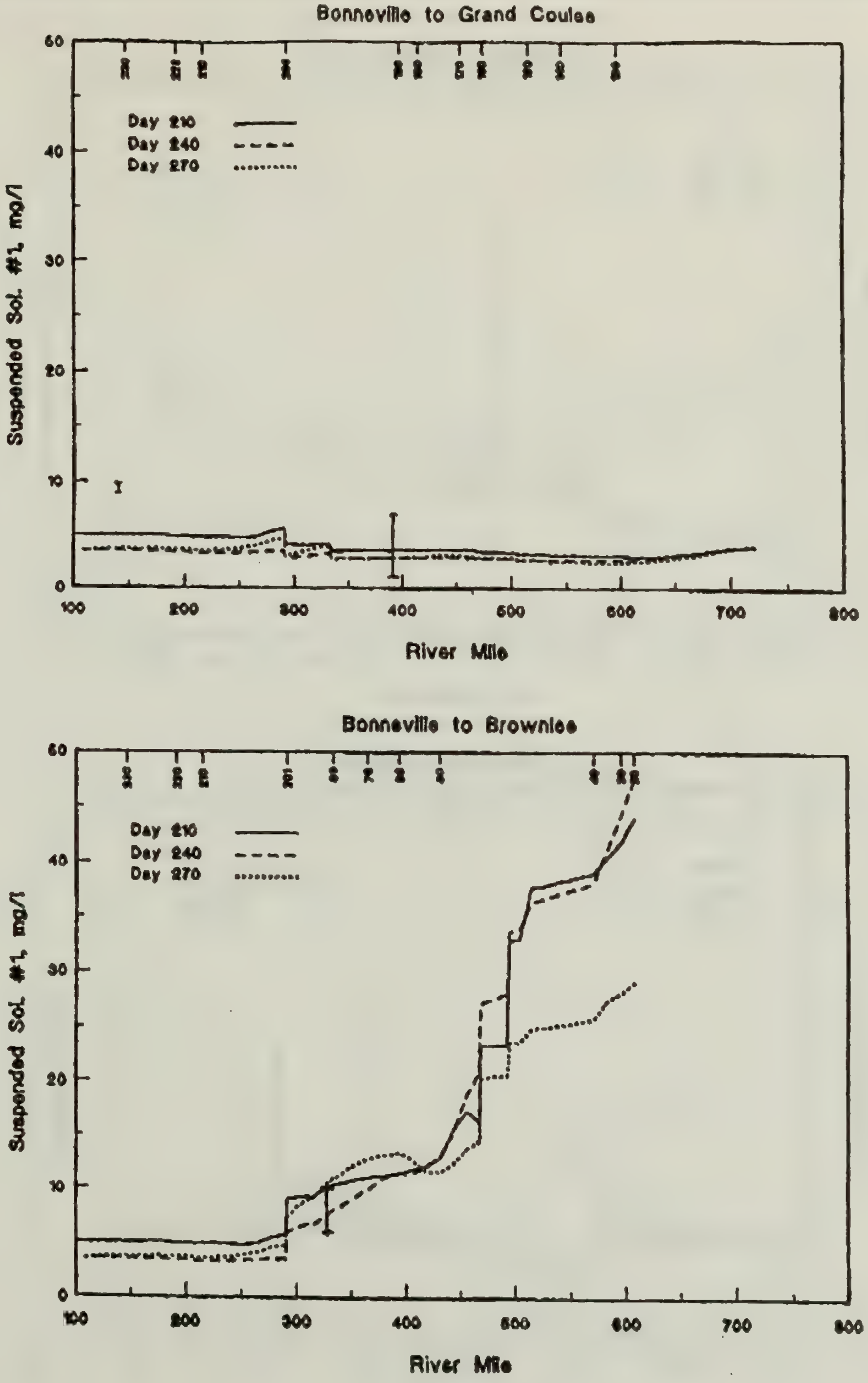


**Figure H–11.** Computed Suspended Solids Profiles In the Columbia and Snake River System Near the End of July, August, and September

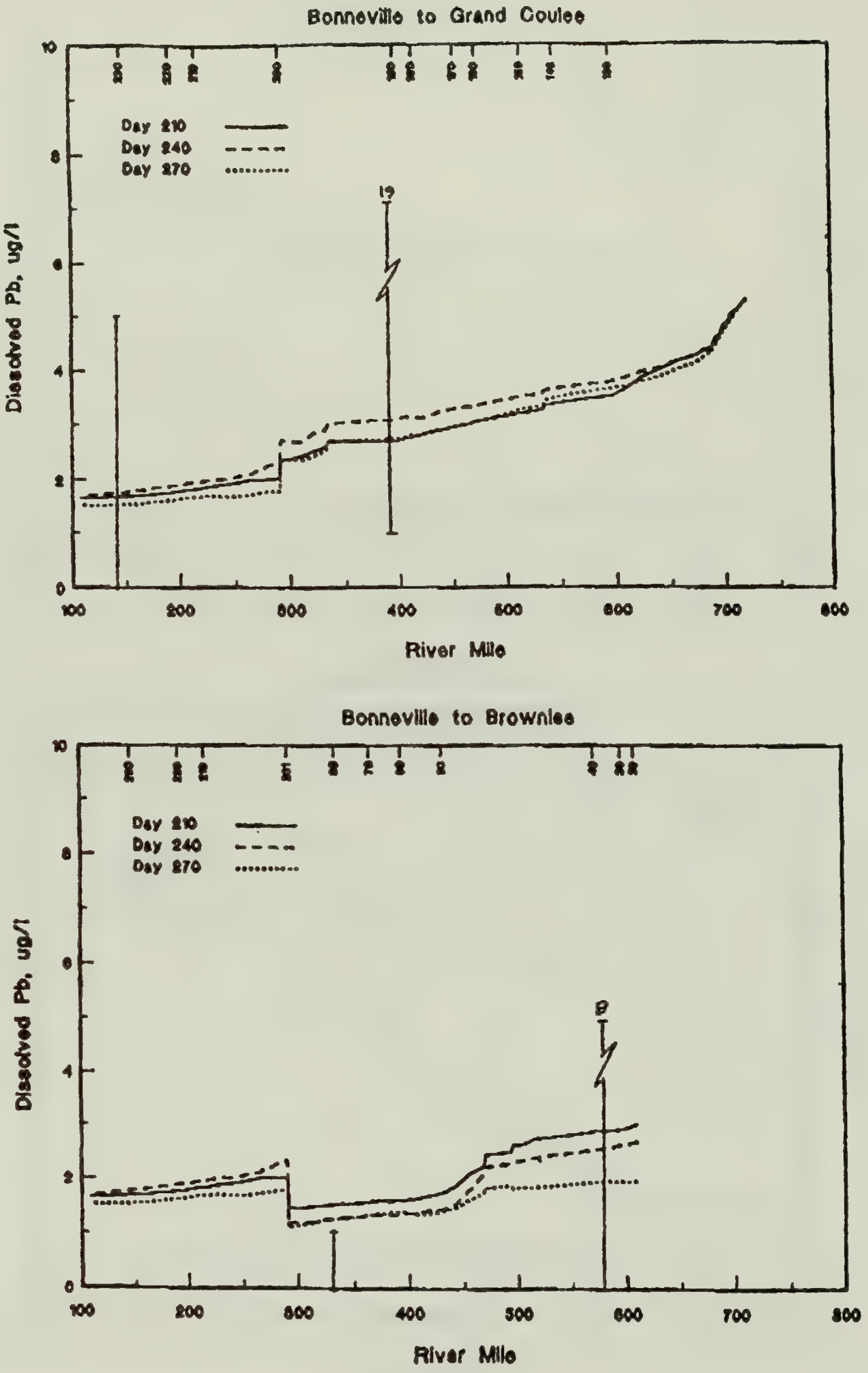


**Figure H–12. Computed Dissolved Lead Profiles in the Columbia and Snake River System Near the End of July, August, and September**

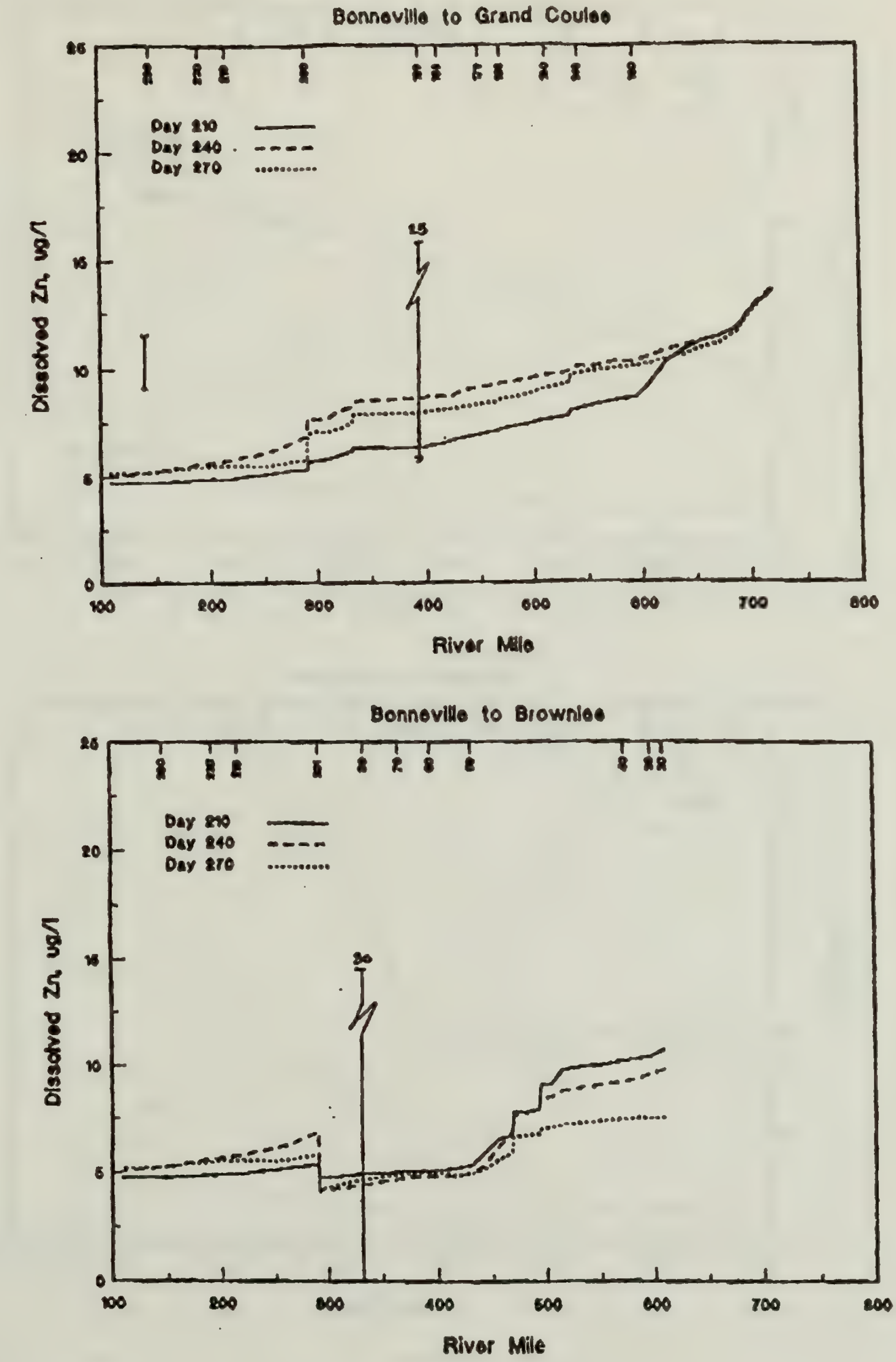


**Figure H–13. Computed Dissolved Zinc Profiles in the Columbia and Snake River System Near the End of July, August, and September**

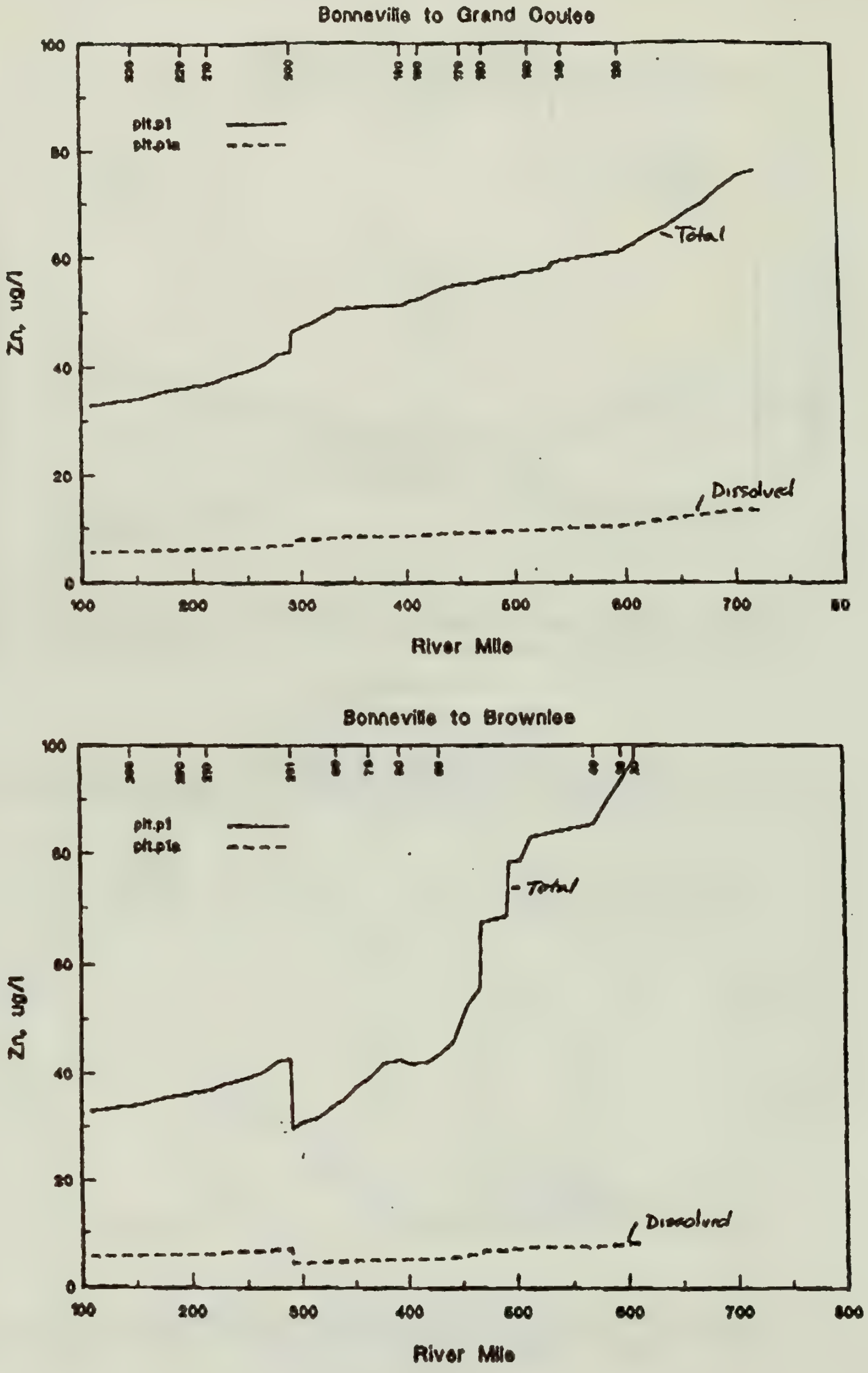


**Figure H–14. Computed Total and Dissolved Zinc Profiles in the Columbia and Snake River System Near the End of July, August, and September**

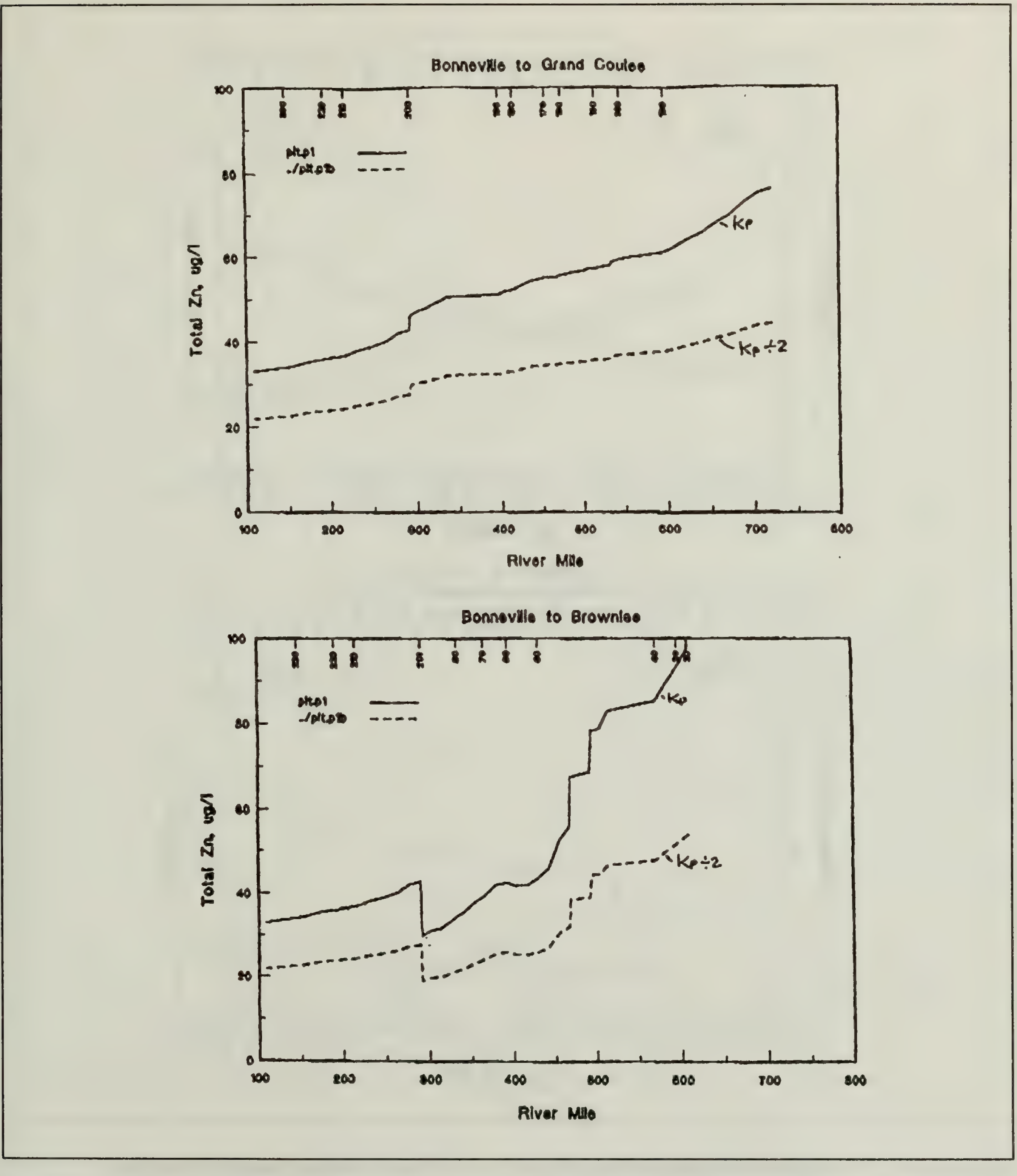


**Figure H–15.** Computed Profiles of Total Zinc in the Columbia and Snake River System Near the End of July, August, and September

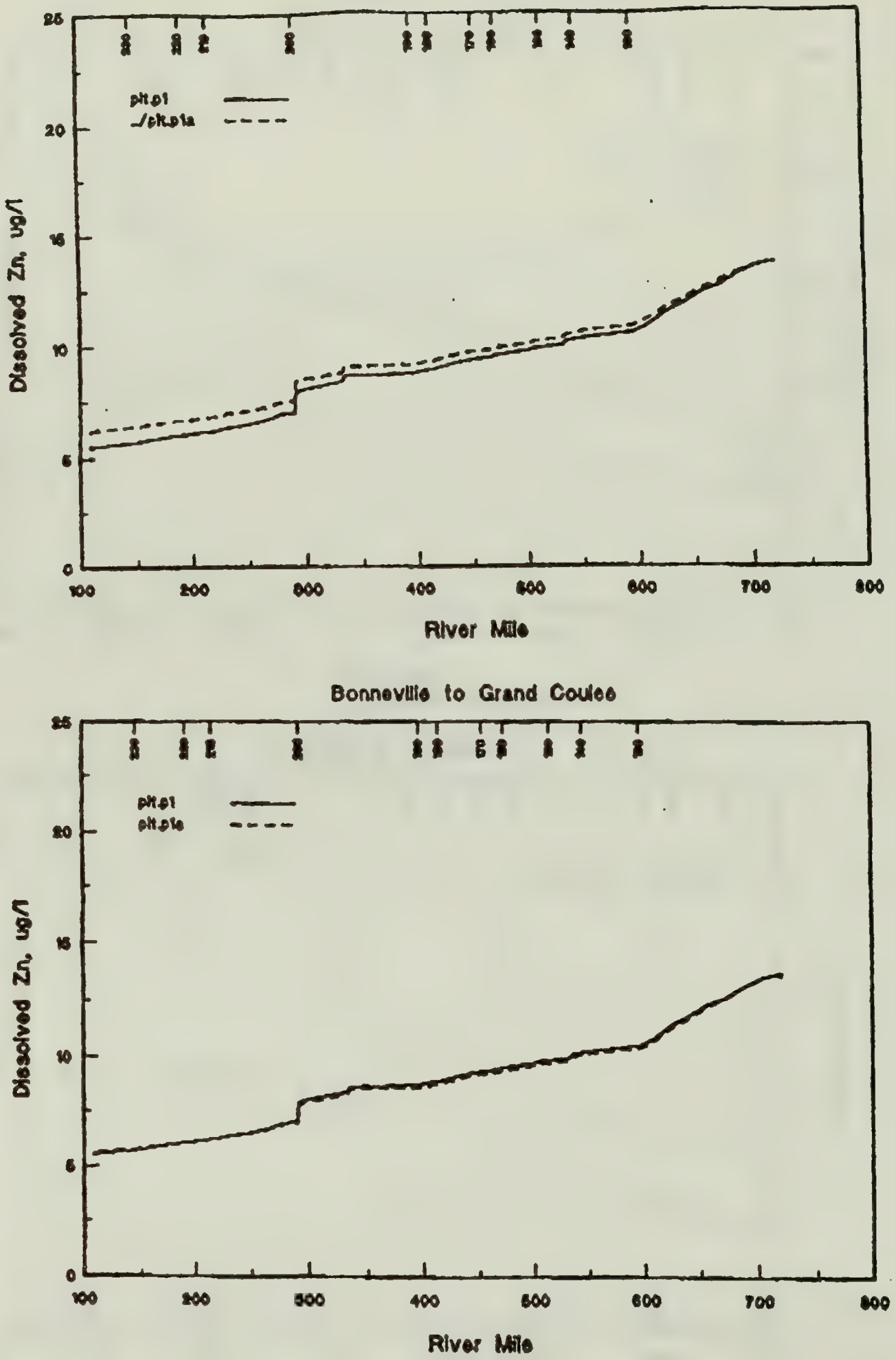


Figure H–16. Computed Profiles of Total Zinc in the Columbia and Snake River for Two Bottom Exchange Rateds (top) and Two Sediment Pore Water Concentrations (bottom)

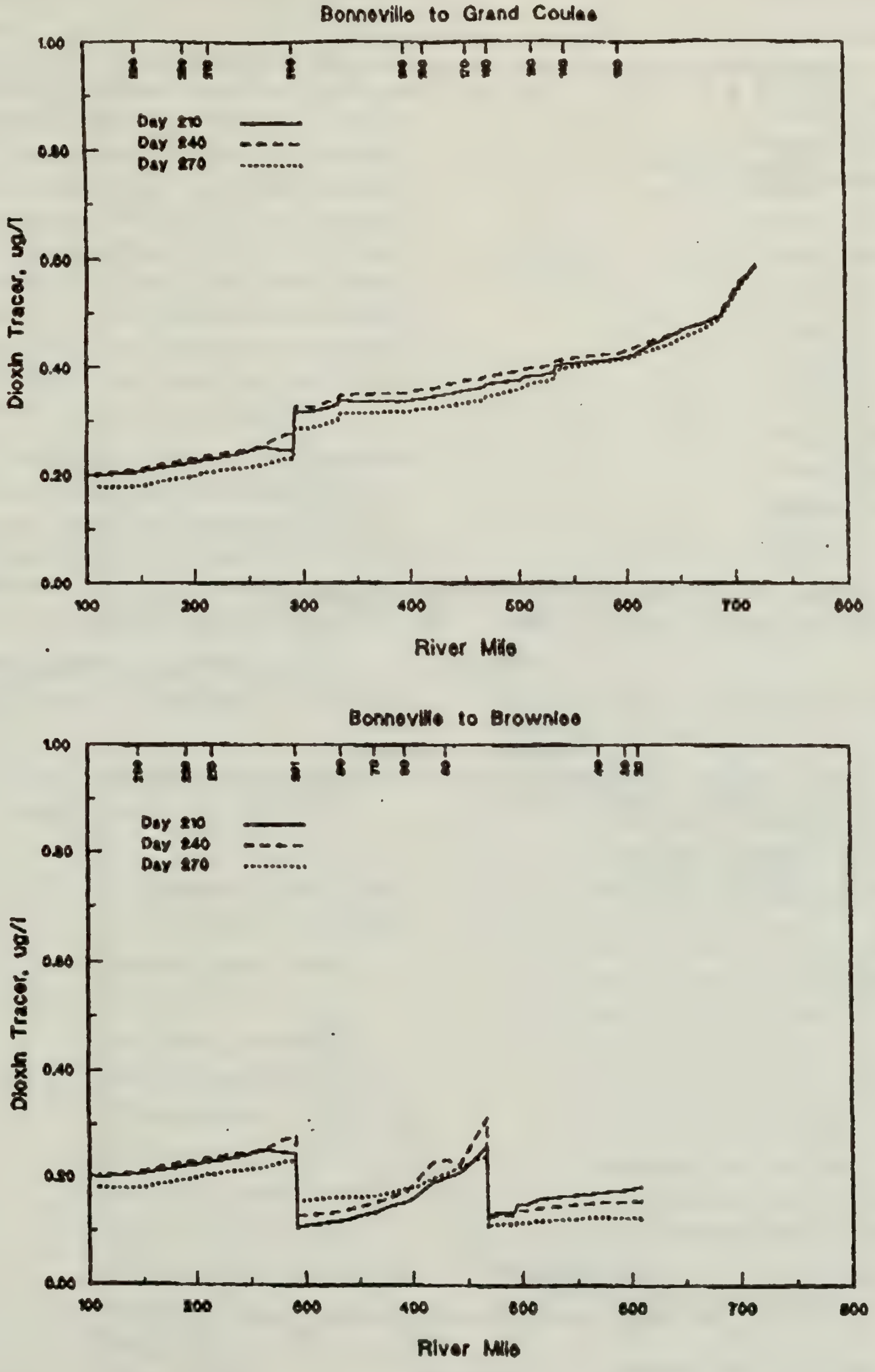


**Figure H–17. Computed Dioxin Tracer Profiles in the Columbia and Snake River System Near the End of July, August, and September**

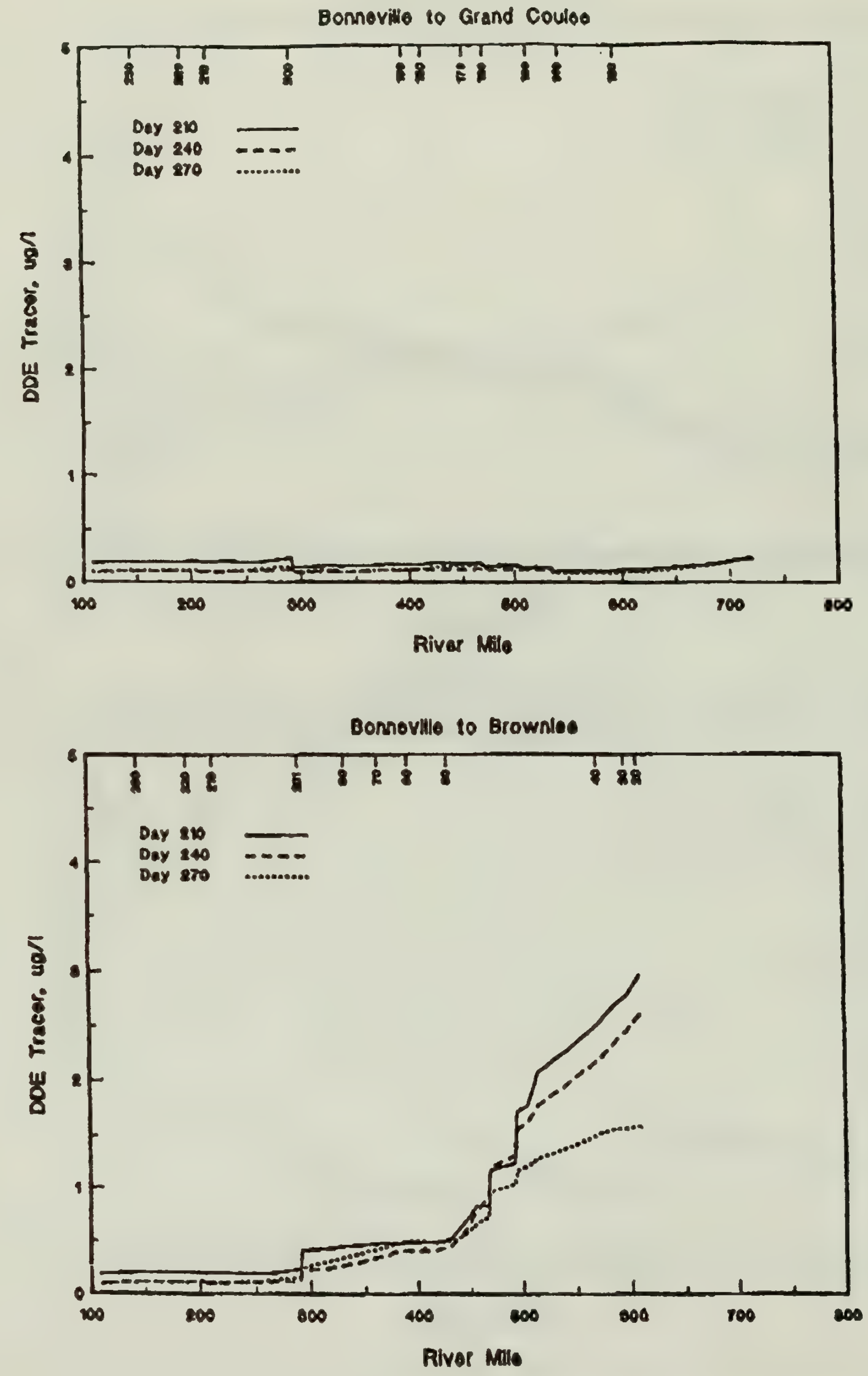


Figure H–18. Computed DDE Tracer Profiles in the Columbia and Snake River System Near the End of July, August, and September

Canadian pulp mills and a pulp mill discharge at the Snake Clearwater confluence. The model results reflect a low decay and volatilization rate and partitioning coefficients somewhat lower that those used in the lead and zinc simulation. These rates result in a slow decline in concentration as flow progresses downstream. The DDE tracer inputs assume elevated concentrations in the Snake River headwater reflecting the high agricultural return component. The model results reflect decay and volatilization rate higher than the dioxin rates. The partitioning coefficients are similar to those assumed for dioxin. These rates result in a more rapid decline in concentration as flow progresses downstream.

Interpretation of model results for these parameters must be limited to evaluating relative impacts of revised system operation. Any reference to these results should stress the relative nature of the computed concentrations. Figures H–12 through H–16 and Figure H–18 are shown in that context only.

## H–9 COMPREHENSIVE WATER QUALITY OPTION (SNAKE– COLUMBIA SYSTEM MODEL)

When the Comprehensive Water Quality option is selected, the following constituents may be simulated:

IPHYTO = 3 = = > Total dissolved solids (treated as a conservative parameter),

Nitrate nitrogen (same as equation 18)*

Phosphate phosphorous (same as equation 19),

Phytoplankton (see modifications below),

Carbonaceous BOD (first order decay parameter),

Ammonia nitrogen (same as equation 22),

Dissolved oxygen (see modifications below),

Chlorides (treated as a conservative parameter),

Alkalinity as $CaCO_3$ (treated as a conservative parameter),

pH (see below)

Total inorganic carbon (see below),

$CO_2$ (see below)

Dissolved organic chemicals, maximum of two (see below),

Heavy metals or radionuclides, maximum of three (see below),

Dioxins or furans, maximum of two (see below),

Organic or inorganic particulates, maximum of three (see below), and

Caliform bacteria (see below),

For each constituent, the distributed heat gain/loss term in equation 9 is replaced by the following terms:

Phytoplankton . . . same as equation 20, with the following exceptions:

1. The light intensity is tied to the three organic or inorganic particulateds and phytoplankton selfshading. Light extinction coefficients for each particulate are supplied by the user.
2. The total nitrogen, total phosphorous and carbon dioxide concentrations are computed (see below). The most limiting factor (nutrient or lght) is used to adjust the growth rate using a Michaelis–Menton formulation as given by equation 21.
3. Respiration and mortality rates are supplkied by the user, and are adjusted to ambient temperature according to equation 7.

Dissolved Oxygen . . . same as equation 23, with the following additions:

1. Suspended organic sediment decay... $-K_1 \bullet [SS] \bullet K_3 \bullet T_{c(T-20)}$

   where

   $K_1$ = decay coefficient for organic particulate,

---

* Equations refered to in this exhibit can be found in HEC publication listed in the reference section.

$[SS]$ = organic particulate concentration (mg/l),

$K_3$ = coefficient to convert from mass of decayed organic particulate to ultimate oxygen demand,

$T_c$ = thermal correction factor for decay of organic particulate, and

$T$ = temperature in degrees Celsius.

A term of this form is included for each organic particulate being simulated.

2. Carbonaceous BOD... − $K_1 \bullet [CBOD] \bullet T_{c(T-20)}$

where

$K_1$ = first order decay coefficient for carbonaceous oxygen demand,

$[CBOD]$ = carbonaceous oxygen demand concentration (mg/l),

$T_c$ = thermal correction factor for decay of [CBOD]

3. Nitrogenous BOD . . . − $K_1 \bullet K_3 \bullet [NH_3-N] \bullet T_{c(T-20)}$

where

$K_1$ = first order decay coefficient for $[NH_3-N]$,

$K_3$ = coefficient to convert from decayed $[NH_3-N]$ to ultimate oxygen demand,

$[NH_3-N]$ = ammonia nitrogen concentration (mg/1),

$T_c$ = thermal correction factor for decay of $[NH_3-N]$

4. Algae respiration and photosynthesis... $\bullet K_2 \bullet (PR + PM) + K_3 \bullet PG$

where

$K_2$ = coefficient to convert from algae respiration rate and algae mortality rate to ultimate oxygen demand,

$K_3$ = coefficient to convert from algae growth rate to photosynthetic oxygen production,

$PR$ = phytoplankton respiration rate,

$PM$ = phytoplankton mortality rate,

$PG$ = phytoplankton growth rate.

Total Inorganic Carbon (TIC) . . .

$$+A_s \bullet K_2 \bullet ([CO_2-C]^* - [CO_2-C]) + K_3 \bullet K_1 \bullet [CBOD] \bullet T_{c\ (T-20)} + K_4 \bullet (PR + PM - PG)$$

where

$A_s$ = element surface area,

$K_2$ = reaeration rate (same as equations 15 and 16),

$[CO_2-C]^*$ = $[CO_2-C]$ saturation concentration at the ambient temperature,

$[CO_2-C]$ = $[CO_2-C]$ concentration,

$K_3$ = coefficient to convert from carbonaceous BOD to ultimate [CO2−C] production,

$K_1$ = first order decay rate for [CBOD],

$T_c$ = thermal correction factor for [CBOD],

$T$ = temperature in degrees Celsius,

$K_4$ = coefficient to convert from net algae growth rate to ultimate $[CO_2-C]$ production.

pH and $CO_2$ . . . computed according to equilibrrium theory considering $CaCO_3$, $CO_2$, $OH^-$ and $H^+$, where $TIC = [CO_2-C] + [CO_{3}-C]$

Dissolved Organic Chemicals...$-K_1 \bullet [ORG]_d - K_2 \bullet [ORG]_d - K_3 \bullet [ORG]_d - \Sigma_{i=1,4} (w_s)_i \bullet ([ORG]_s)_i/DEP - K_4([ORG]_d - [ORG]_P)/DEP$

where

$K_1$ = first order decay coefficient for the dissolved organic chemical,

$K_2$ = first order violation coefficient for the dissolved organic chemical (i.e., volatilization rate in m/sec divided by depth),

$K_3$ = first order complexation/precipitation coefficient for the dissolved organic chemical,

$[ORG]_d$ = dissloved organic chemical concentration,

$([ORG]_s)_i$ = for i = 1 . . 3, sorbed organic chemical concentration assoiated with i^th organic or inorganic particulate,

= for i = 4, sorbed organic chemical concentration associated with phyoplankton,

DEP = depth of the water column

$(w_s)_i$= for i = 1 . . 3, setting velocity of i^th organic or inorganic particulate,

= for i = 4, setting velocity of phytoplankton,

$K_4$ = diffusion rate between the sediment pore water and the overlying water,

$[ORG]_P$ = dissolved organic chemical in the sediment pore water.

The dissolved and sorbed fractions of the dissolved organic chemical is determined according to the solution of the following simultaneous equations:

$[ORG] = [ORG]_d(1+\Sigma_{i=1,4} (K_5)_i \bullet [SS]^{\alpha}_i)$
and $[ORG] = [ORG]_d + [ORG]_s$

where

$(K_5)_i$ = partitioning coefficient for the organic chemical with the i^th organic or inorganic particulate (l/m^2),

$[SS]_i$ = concentration of i^th organic or inorganic particulate (mg/l)

α = exponent

An iterative process is used to solve for [ORG]s and $[ORG]_d$.

Associated with the water column model is a sediment bed model. The bed model represents that portion of the reservoirs amd stream, bottom which interacts with the overlying water through diffusion of the dissolved organic chemicals in the pore water. A partitioning coefficient similar to that described above is used to compute the pore water concentration as a function of total mass of the pullutant contained in the bed. Fluxes to and from the bed model mirror the last two terms of the equation describing dissolved orgnaic chemical kinetics with the exception that the sediment concentration exponent is always 1. The bed thickness is assumed constant and burial rate is equal to the suspended sediment settling flux.

Heavy Metals or Radionuclides . . .
$- K_1 \bullet [HMT]_d - K_3 \bullet [HMT]_d \bullet \Sigma_{i=1,4} (w_s)_i \bullet ([HMT]_s)_i/DEP - K_4 ([HMT]_d - [ORG]_P)/DEP$

where

$K_1$ = first order decay coefficient for radionuclide (= 0 if heavy metal),

$K_3$ = first order complexation /precipitation coefficient for heavy metal or radionuclide,

$[HMT]_d$ = dissolved heavy metal or radionuclide concentration,

$([HMT]_s)_i$ = for i = 1 . . 3, sorbed heavy metal or radionuclide concentration associated with ith organic or inorganic particulate.

= for i = 4, sorbed heavy metal or radionuclide concentration associated with phytoplankton.

DEP = depth of the water column

$(w_s)_i$ = for i = 1 . . 3, settling velocity of $i^{th}$ organic or inorganic particulate.

= for i = 4, settling velocity of phytoplankton.

$K_4$ = diffusion rate between the sediment pore water and the overlying water,

$[HMT]_p$ = heavy metals in the sediment pore water.

The dissolved and sorbed fractions of the heavy metal or radionuclide are determined according to the solution of the following simultaneous equations:

$$[HMT] = [HMT]_d(1 + \Sigma_{i=1,4} (K_5)i \bullet [SS]^{\alpha}_i)$$

$$\text{and } [HMT] = [HMT]_d + [HMT\}_s$$

where

$(K_s)i$ = partioning coefficient for the heavy metal or radionuclide with the $i^{th}$ organic or inorganic particulate ($l/m^2$),

$[SS]_i$ = concentration of $i^{th}$ orgnaic or inorganic particulate (mg/l),

$\alpha$ = exponent

An iterative process is used to solve for $[HMT]_s + [HMT]_d$.

A bed model is used to compute the concentration of heavy metals in the sediment pore water and is similar to the bed model described for dissolved organic chemicals.

Dioxin or furan...$-K_1 \bullet [DIO]_d - K_3 \bullet [DIO]_d - \Sigma_{i=1,4} (w_s)i \bullet ([DIO]_s)i/DEP - K_4 ([DIO]_d - [DIO]_p)/DEP$

where

$K_1$ = first order decay coefficient for dioxin or furan,

$K_3$ = first order complexation/precipitation coefficient for dioxin or furan,

$[DIO]_d$ = dissolved dioxin or furam concentration,

$([DIO]_s)_i$ = for i = 1 . . 3, sorbed dioxin or furan concentration associated with $i^{th}$ organic or inorganic particulate.

= for i = 4, sorbed dioxin or furan concentration associated with phytoplankton,

DEP = depth of the water column

$(w_s)_i$ = for i = 1 . . 3, settling velocity of $i^{th}$ organic or inorganic particulate.

= for i = 4, settling velocity of phytoplankton.

$K_4$ = diffusion rate between the sediment pore water and the overlying water,

$[DIO]_p$ = dioxin or furan in the sediment pore water.

The dissolved and sorbed fractions of the dioxin or furan is determined according to the solution of the following simultaneous equations:

$$[DIO]_5 = [DIO]_d(1 + \Sigma_{i=1,4} (K_5)i \bullet [SS]^{\alpha}_i)$$

$$\text{and } [DIO] = [DIO]_d + (DIO)_s$$

Where

$(K_s)_i$ = partioning coefficient for the dioxin or furan with the $i^{th}$ organic or inorganic particulate ($l/m^2$),

$[SS]_i$ = concentration of $i^{th}$ organic or inorganic particulate (mg/l),

$\alpha$ = exponent

An iterative process is used to solve for $[DIO]_s + [DIO]_d$.

A bed model is used to compute the concentration of dioxin and furans in the sediment pore water and is similar to the bed model described for dissolved organic chemicals.

Organic or Inorganic Particulate.. $- w_s \bullet K_5 \bullet A_s[SS] - K_1 \bullet [SS] \bullet T_{c(T-20)}$

where

$w_s$ = settling velocity for organic or inorganic particulate, where $w_s = a_0 + a_1 \bullet T + a_2 \bullet T^2$

$a_0, a_1, a_2$ = quadratic coefficients for function defined by three pairs of $(T, w_s)$ data.

$K_5$ = loss coefficient computed according to Rouse velocity distribution,

$A_s$ = element surface area,

$[SS]$ = organic or inorganic particulate concentration,

$K_1$ = first order decay coefficient for organic particulate ( = 0 for inorganic particulate),

$T_c$ = thermal correction factor for organic or inorganic particulate.

Coliform Bacteria . . . $- K_1 \bullet [CB] \bullet T_{c(T-20)}$

$K_1$ = first order mortality rate for coliform bacteria,

$[CB]$ = coliform bacteria concentration,

$T_c$ = thermal correction factor for coliform mortality.

## H–10 SAMPLES OF WATER TEMPERATURES PREDICTIONS

Figures H–19 through H–24 are provided to reflect the range of accuracy achieved in modeling water temperature in Columbia and Snake River reservoirs and river reaches. The first two figures refer to the reconstitution of water temperature profiles at Dworshak Reservoir for June–September 1991. The next three graphs represent daily simulation of water temperatures at Ice Harbor, Priest Rapids, and The Dalles for 1984, 1985 and 1990. As is evident from a cursory review of the plots provided, simulation accuracy varies from year to year, and from location to location. It depends largely on how representative of actual conditions data used for model input are. The most important input data include initial water temperature conditions at the start of the model run (usually 1 April), and the weather information that determines the heat loss/gain process.

REFERENCE – US Army Corps of Engineers, Hydrologic Engineering Center, Davis, California, 1989. HEC–5 Simulation of Flood Control and Conservation Systems. Appendix on Water Quality Analysis. September 1986.

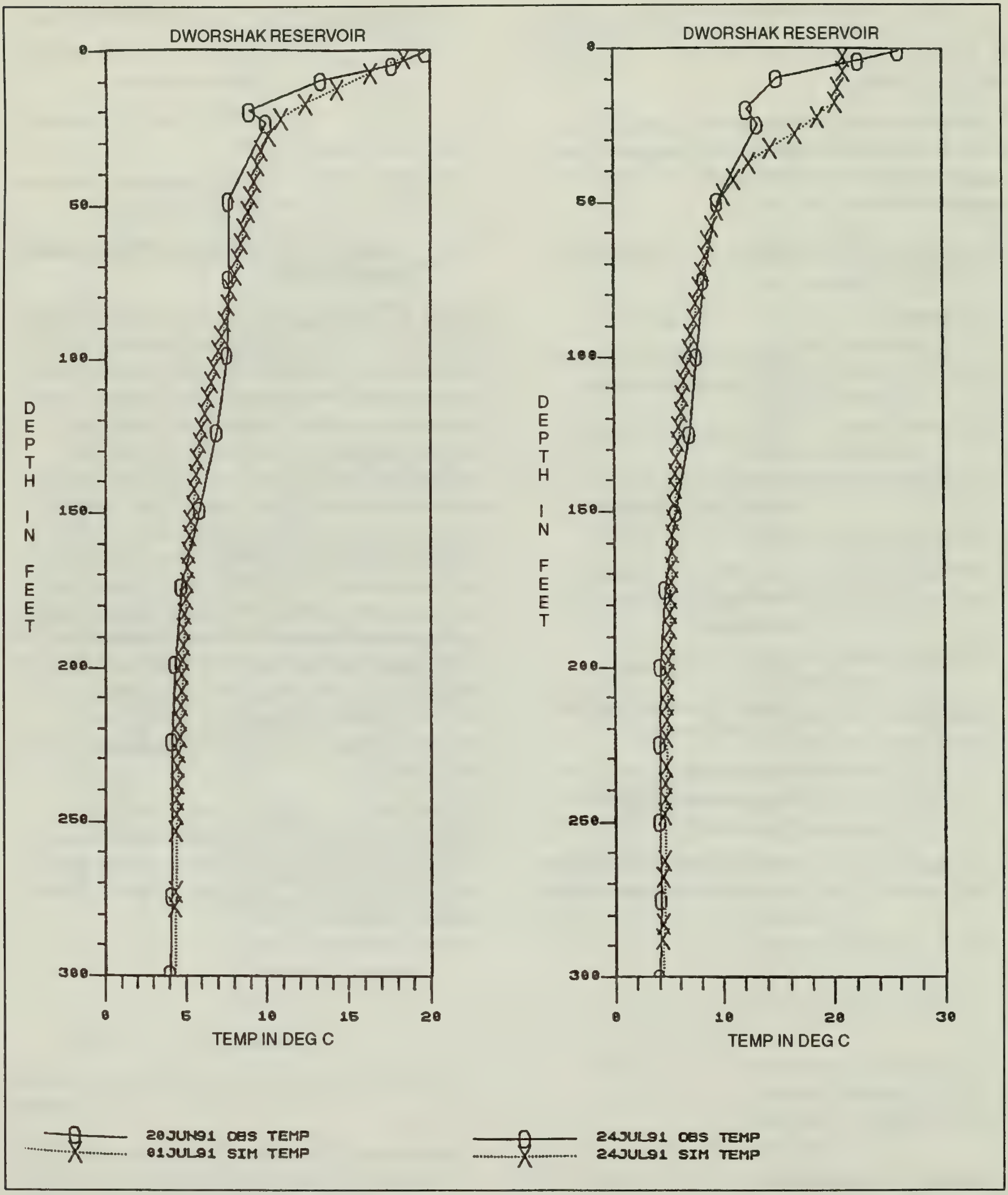


**Figure H–19. Water Temperature Profiles, Dworshak Reservoir June and July 1991**

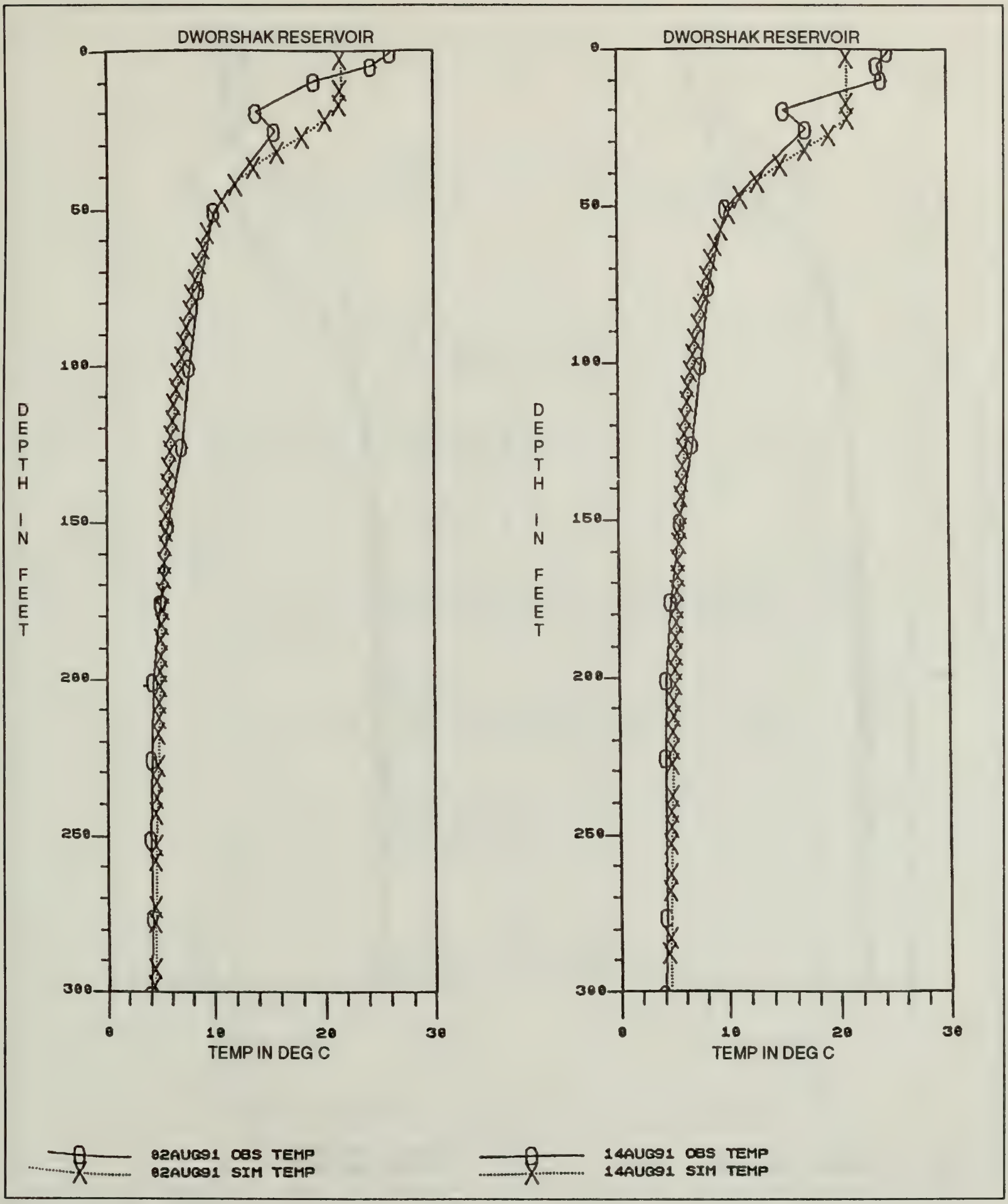


**Figure H–20. Water Temperature Profile, Dworshak Reservoir August 1991**

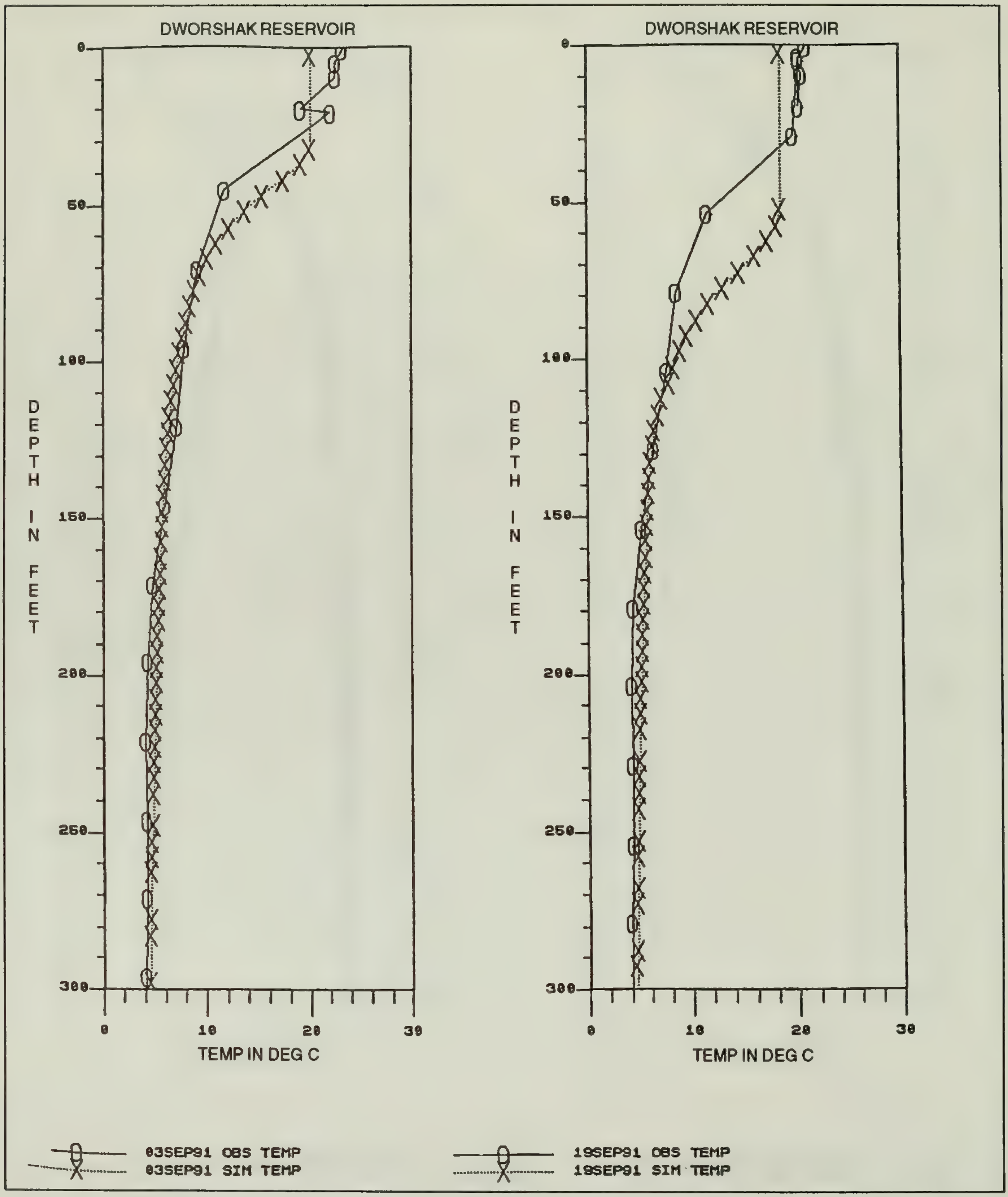


**Figure H–21. Water Temperature Profile, Dworshak Reservoir September 1991**

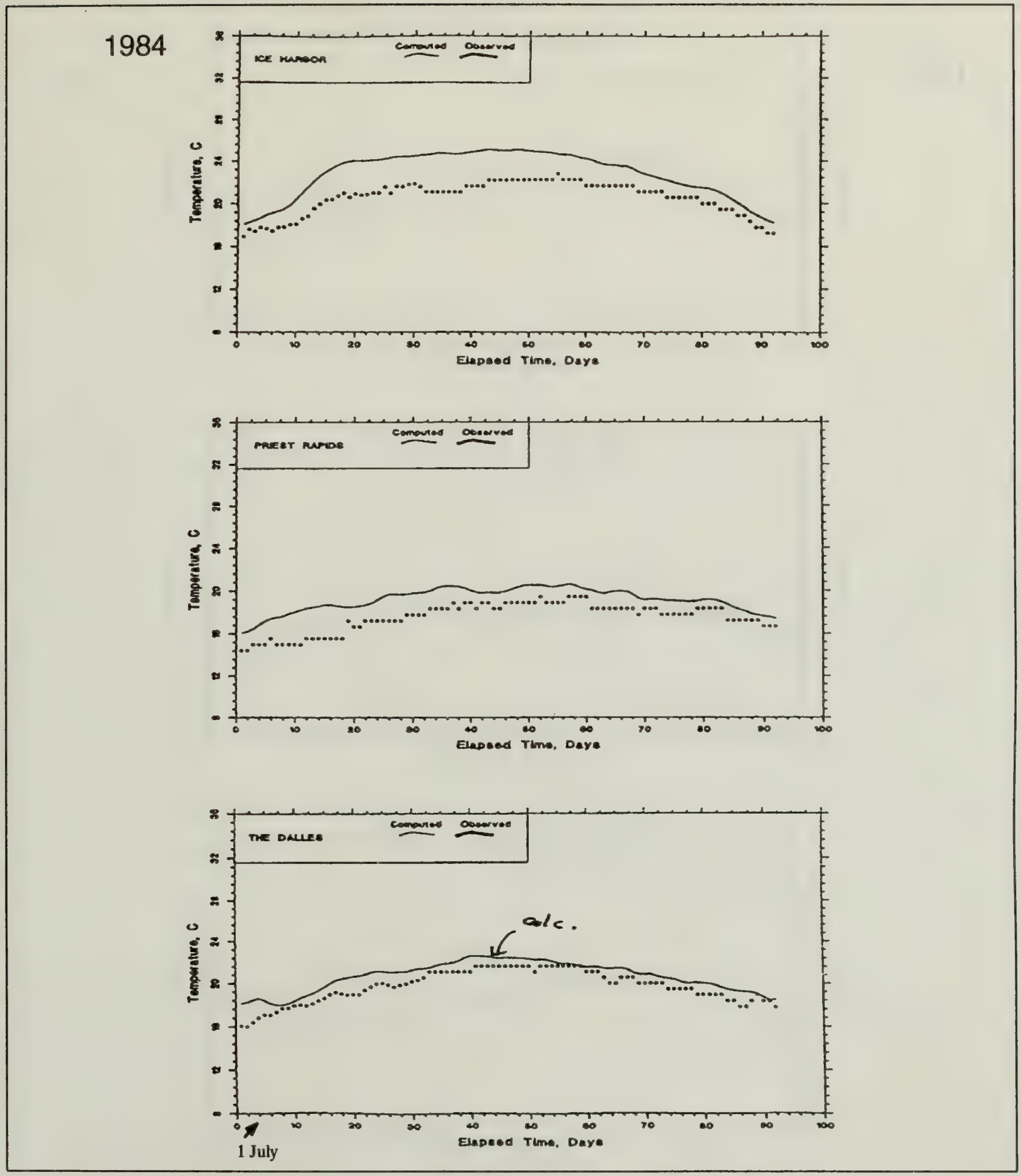


**Figure H–22. Water Temperatures (1984) for Ice Harbor, Priest Rapids and The Dalles Forebays (15' depth)**

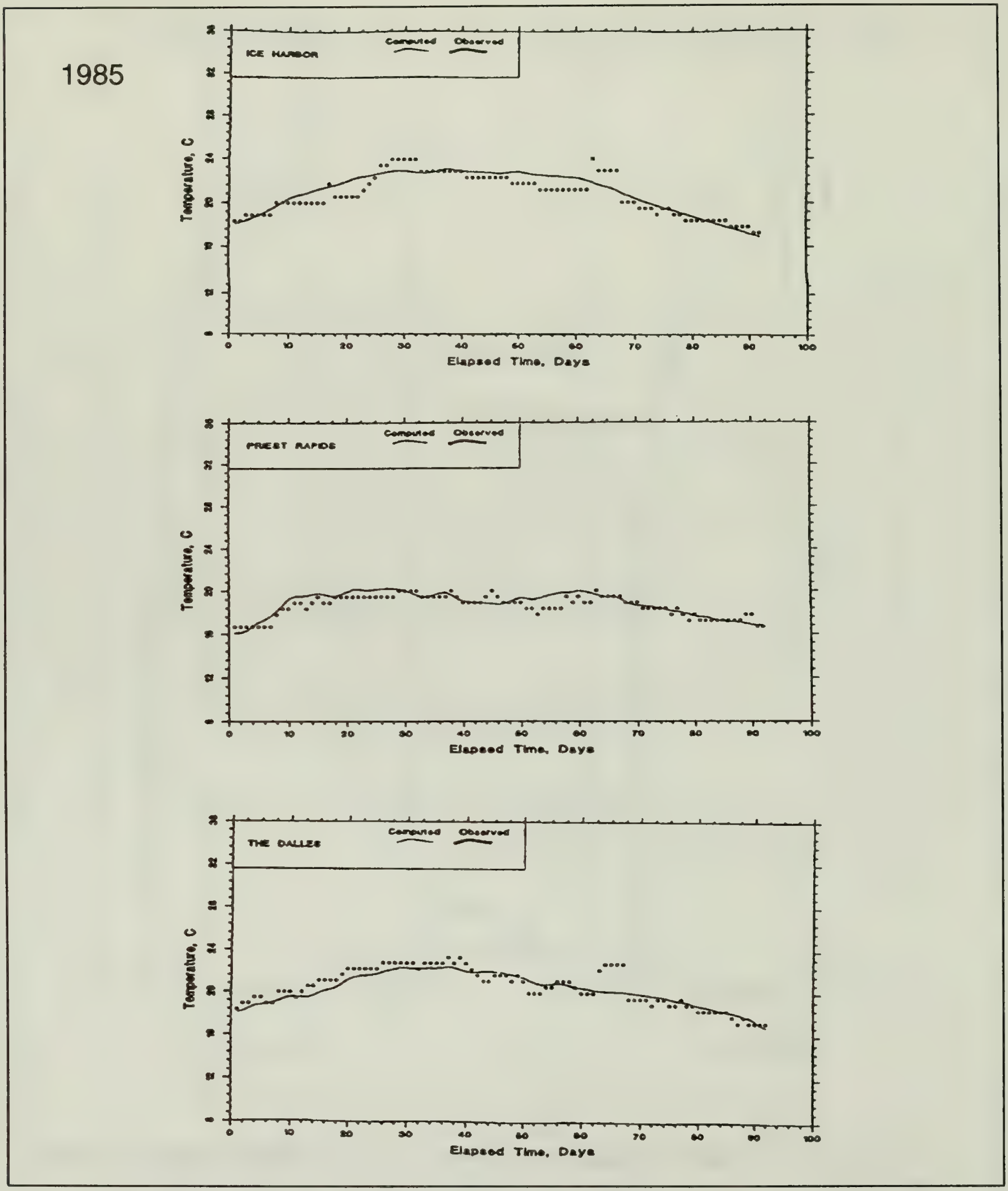


**Figure H–23. Water Temperatures (1985) for Ice Harbor, Priest Rapids and The Dalles**

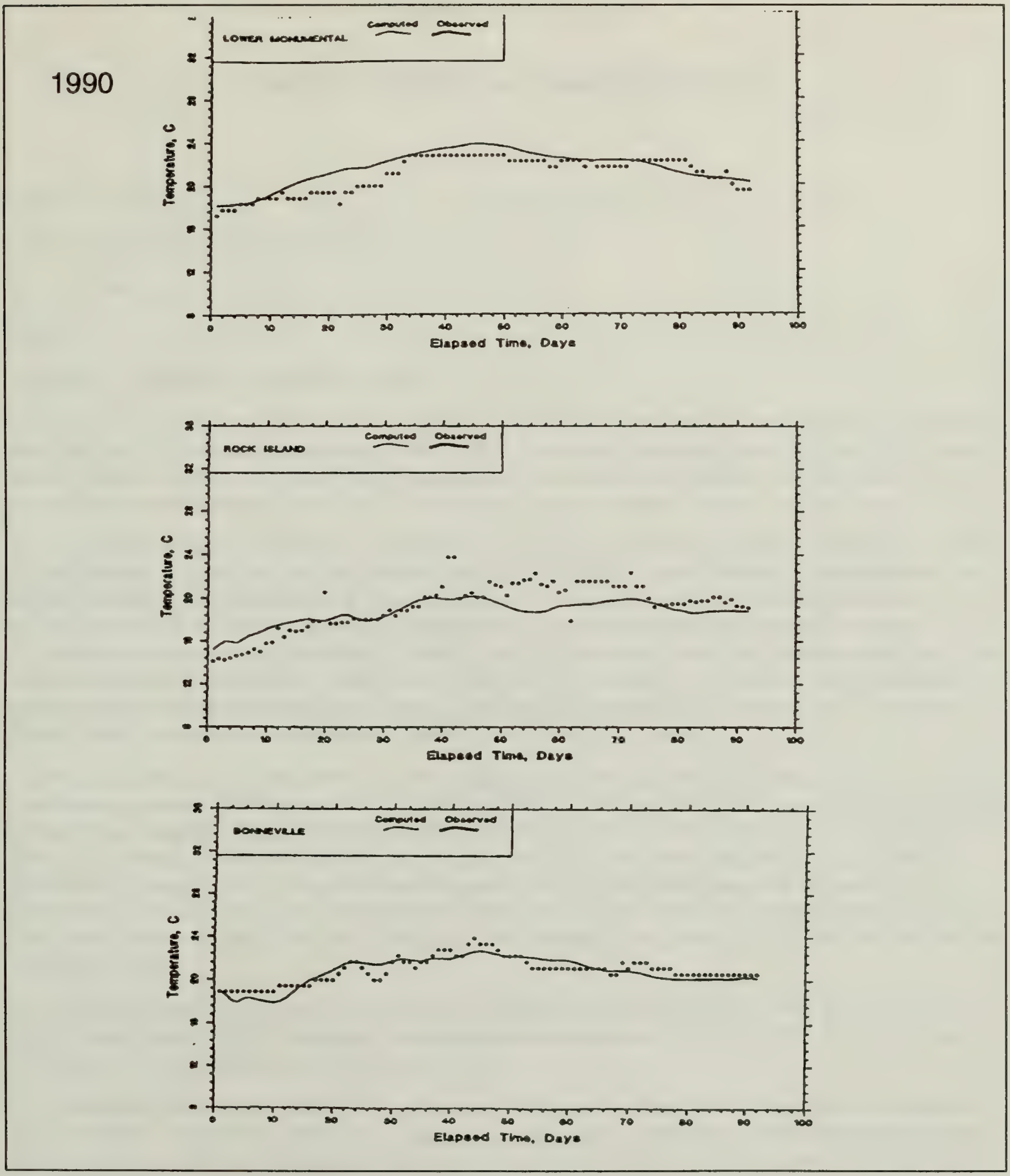


**Figure H–24. Water Temperatures (1990) for Lower Monumental, Rock Island, and Bonneville**

## TECHNICAL EXHIBIT I

## GASSPILL MODEL CALIBRATION RESULTS

CENPD–PE–WM December 15, 1992

MEMORANDUM FOR THE RECORD

From : Bolyvong Tanovan

To: File

SUBJECT: Calibration of GASSPILL Model

1. For use in the Columbia River System Operation Review (SOR), subject model was recalibrated using 1984 and 1986 data. The original program as modified by OTT Engineers was reinstalled on the AMDAHL mainframe computer as well as on a PC. This program has been compiled the year before, the first time it has been revived since Ott worked on it circa 1987. There has just been no practical need for running it before.

2. An auxiliary program (GASSPILL.AUXI1.CNTL) was written to facilitate model recalibration by calculating daily means from the base file such as G0TKA.POST80.DATA for use as reference. Calibration centered around the three C coefficients used in the calculation of the entrainment KT in subroutine DAM. The C values are stored in the BLOCK DATA file. Repeated model use in the calibration requires that these values be read in as input from a file (GASSPILL.TEMP.C.DATA), rather than having the model recompile each time a C value is changed. A temporary output file (GASSPILL.FILE21.DATA) is created for each run, with data used in subsequent calculation of the KT values. Plotting scales have also been enlarged, with Y axis values from 90 to 140 percent as opposed to the original range of 50 to 150 percent.

Calibration starts from CHJ and LWG on down, reach by reach wherever observed TDG data exist. In 1984, there were no observed TDG data at WAN, LMN and BON. In 1986, only WAN data were missing. At the end of each run, a temporary file, GASSPILL.FILE21.DATA, is captured on a floppy which in turn is read by an optimizing program, GAS–OPT.BAS, for the dam of interest. The sum of squared error (CAL–OBS)**2 is minimized by changing the Cs using the steepest–ascent method. The best C values for the dam being optimized are re–entered in the GASSPILL.TEMP1.C.DATA file. A new GASSPILL model run is then made, from which another temporary file will be created. A new calculation loop will begin with emphasis on the next downstream dam.

IHR is calibrated based on data at MCN–O. PRD is calibrated based on data at MCNW. Incoming TDG for MCN before routing to JDA is calculated as weighted average between Q(PRD), Q(IHR), TDG(PRD) and TDG(IHR). For BON, tailwater TDG was from WRN.

3. Calculated TDG using the old Cs are undercomputed (lower than observed). Those generated with optimized C values correct that problem. A summary of C values is given in Table 1. Predicted TDGs, although not perfect, are encouraging and reasonable, given the fact that we are dealing with daily means and the widely variable TDG values. Some instrument errors may be involved, but they are hard to weed out systematically. By looking at daily values, some of the clearly unrealistic peaks and valleys have been smoothed out to some extent. By and large, data collected at RIS and PRD appear to be comparatively less reliable.

Precision of the calibration is given in Table 2. Most of the observed TDG were replicated within 10 percent of their actual values.

C values derived from 1984 and 1986 calibration runs are different. We decided to give more reliance on 1986 data and consequently more weight to the C values from that year. The recommended C values are weighted(C84x1° + C86x2)/(1+2). Sec Table I–1, last column.

### Table I–1. Summary of C Values

| | ORI | 84-OPTIM | 86-OPTIM | WEIGHTED |
|---|---|---|---|---|
| C1: | | | | |
| BON | 2.46878 | 2.44831 | 2.24698 | 2.307379 |
| TDA | 34.88983 | 34.88983 | 39.01794 | 37.77951 |
| JDA | 4.53032 | 4.33012 | 5.75619 | 5.32869 |
| MCN | 3.30868 | 3.30868 | 3.30868 | 3.30868 |
| IHR | .52422 | -.02030 | -0.35793 | -0.25664 |
| LMN | 3.30868 | 3.96820 | 4.48211 | 4.327937 |
| LGS | 5.00000 | 5.00000 | 3.84712 | 4.192984 |
| LWG | 0.00000 | 0.29331 | -0.09019 | 0.02486 |
| PRD | 5.52325 | 6.94530 | 8.47838 | 8.018456 |
| WAN | -6.01923 | -3.61309 | -7.78618 | -6.53425 |
| RIS | -5.38968 | -2.75251 | -0.69993 | -1.3157 |
| RRH | 1.39023 | 3.50840 | -2.39560 | -0.6244 |
| WEL | -2.09377 | -2.09380 | -7.21652 | -5.6797 |
| CHJ | -1.38120 | -1.38120 | 1.03145 | 0.307655 |
| C2: | | | | |
| BON | 1.10828 | 1.97313 | 4.15004 | 3.496967 |
| TDA | -.82676 | -.82676 | -0.83715 | -0.83403 |
| JDA | .91349 | .91349 | -1.12984 | -0.51684 |
| MCN | .40545 | .40545 | 0.40545 | 0.40545 |
| IHR | .14623 | .14623 | 0.14623 | 0.14623 |
| LMN | .40545 | .40545 | 0.40545 | 0.40545 |
| LGS | .40545 | .40545 | 1.25669 | 1.001318 |
| LWG | .90172 | .90172 | 0.90172 | 0.90172 |
| PRD | -.34500 | -.70622 | -1.05475 | -0.95019 |
| WAN | .03090 | .03378 | 1.59274 | 1.125052 |
| RIS | -0.13676 | -.13676 | -0.14555 | -0.14291 |
| RRH | .11368 | .11350 | 0.11350 | 0.11350 |
| WEL | 0.69094 | 1.38400 | 1.38400 | 1.38400 |
| CHJ | 1.92208 | 1.92208 | 1.92260 | 1.922444 |
| C3: | | | | |
| BON | -1.10325 | -1.11822 | -1.11822 | -1.11822 |
| TDA | -.29813 | -.29813 | -0.30908 | -0.3058 |
| JDA | -.03730 | -.03730 | -0.03034 | -0.03243 |
| MCN | -.03201 | -.03201 | -0.03201 | -0.03201 |
| IHR | -.00388 | -.00388 | -0.00388 | -0.00388 |
| LMN | -.03201 | -.03470 | -0.03470 | -0.0347 |
| LGS | -.03201 | -.03201 | -0.04524 | -0.04127 |
| LWG | 0.00000 | 0.00000 | 0.00000 | 0.0 |
| PRD | -.03310 | -.03310 | -0.03310 | -0.0331 |

## Table I–1. Summary of C Values – CONT

| | | | | |
|---|---|---|---|---|
| WAN | .05233 | .05521 | 0.04408 | 0.047419 |
| RIS | .05063 | .05062 | 0.04168 | 0.044362 |
| RRH | 0.00000 | 0.00000 | 0.00000 | 0.0 |
| WEL | .01921 | .01921 | 0.01921 | 0.01921 |
| CHJ | 0.0000 | 0.0000 | -0.00890 | -0.00623 |

## Table I–2. Precision of Model Calibration (5/15-7/26: 73 days)

Values in columns refer to predicted forebay mean daily TDG within:

(1) Less than 5% of observed values

(2) Between 5 and 10%, and

(3) Greater than 10%

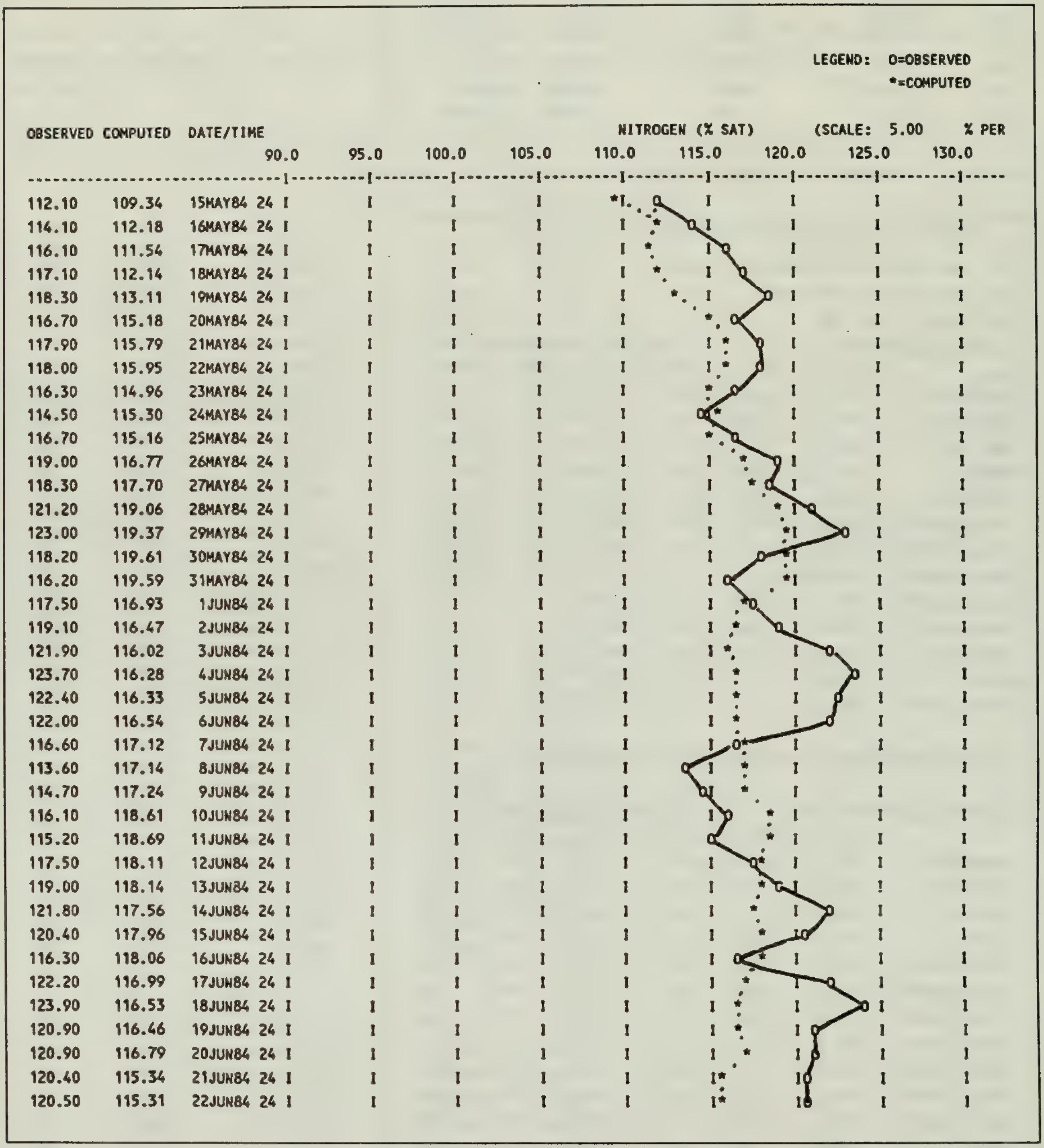
| A. 1984 Calibration | | | | B. 1986 Calibration | | |
|---|---|---|---|---|---|---|
| Dams | (1) | (2) | (3) | (1) | (2) | (3) |
| BONNEVILLE | 43.8 | 54.8 | 1.4 | 79.5 | | |
| THE DALLES | 93.2 | 6.8 | 0.0 | | | |
| JOHN DAY | 86.3 | 13.7 | 0.0 | 64.4 | | |
| MCNARY | 87.7 | 12.3 | 0.0 | 72.6 | | |
| ICE HARBOR | 86.3 | 13.7 | 0.0 | 86.3 | | |
| LOWER MONUMENTAL | 56.2 | 32.9 | 10.9 | 74.0 | | |
| LITTLE GOOSE | 87.7 | 12.3 | 0.0 | 87.7 | | |
| LOWER GRANITE | 100.0 (*) | | | | | |
| PRIEST RAPIDS | 50.7 | 42.5 | 6.8 | 82.8 | | |
| ROCK ISLAND | 98.6 | 1.4 | 0.0 | 88.7 | | |
| ROCKY REACH | 100.0 | 0.0 | 0.0 | 90.3 | | |
| WELLS | 100.0 | 0.0 | 0.0 | 51.1 | | |
| CHIEF JOSEPH | 100.0 (*) | | | | | |

(*) observed=computed, by definition, at headwater sites

| C. 1984 Using Optimized C | | | | D. 1986 Using Optimized C | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (1) | (2) | (3) |
| BONNEVILLE | 53.4 | 45.2 | 0.0 | 72.8 | 27.4 | 0.0 |
| THE DALLES | 89.0 | 11.0 | 0.0 | 76.7 | 20.5 | 2.7 |
| JOHN DAY | 86.3 | 13.7 | 0.0 | 68.5 | 31.5 | 0.0 |
| MCNARY | 84.9 | 15.1 | 0.0 | 72.6 | 21.9 | 5.5 |
| ICE HARBOR | 93.2 | 6.8 | 0.0 | 86.3 | 12.3 | 1.4 |
| LOWER MONUMENTAL | 78.1 | 20.5 | 1.4 | 71.2 | 28.8 | 0.0 |
| LITTLE GOOSE | 90.4 | 9.6 | 0.0 | 87.7 | 12.3 | 0.0 |
| LOWER GRANITE | 100.0 (*) | | | | | |
| PRIEST RAPIDS | 49.3 | 30.1 | 20.5 | 82.8 | 17.2 | 0.0 |
| ROCK ISLAND | 84.9 | 15.1 | 0.0 | 83.9 | 16.1 | 0.0 |
| ROCKY REACH | 93.2 | 6.8 | 0.0 | 90.3 | 9.7 | 0.0 |
| WELLS | 100.0 | 0.0 | 0.0 | 51.1 | 48.9 | 0.0 |
| CHIEF JOSEPH | 100.0 (*) | | | | | |

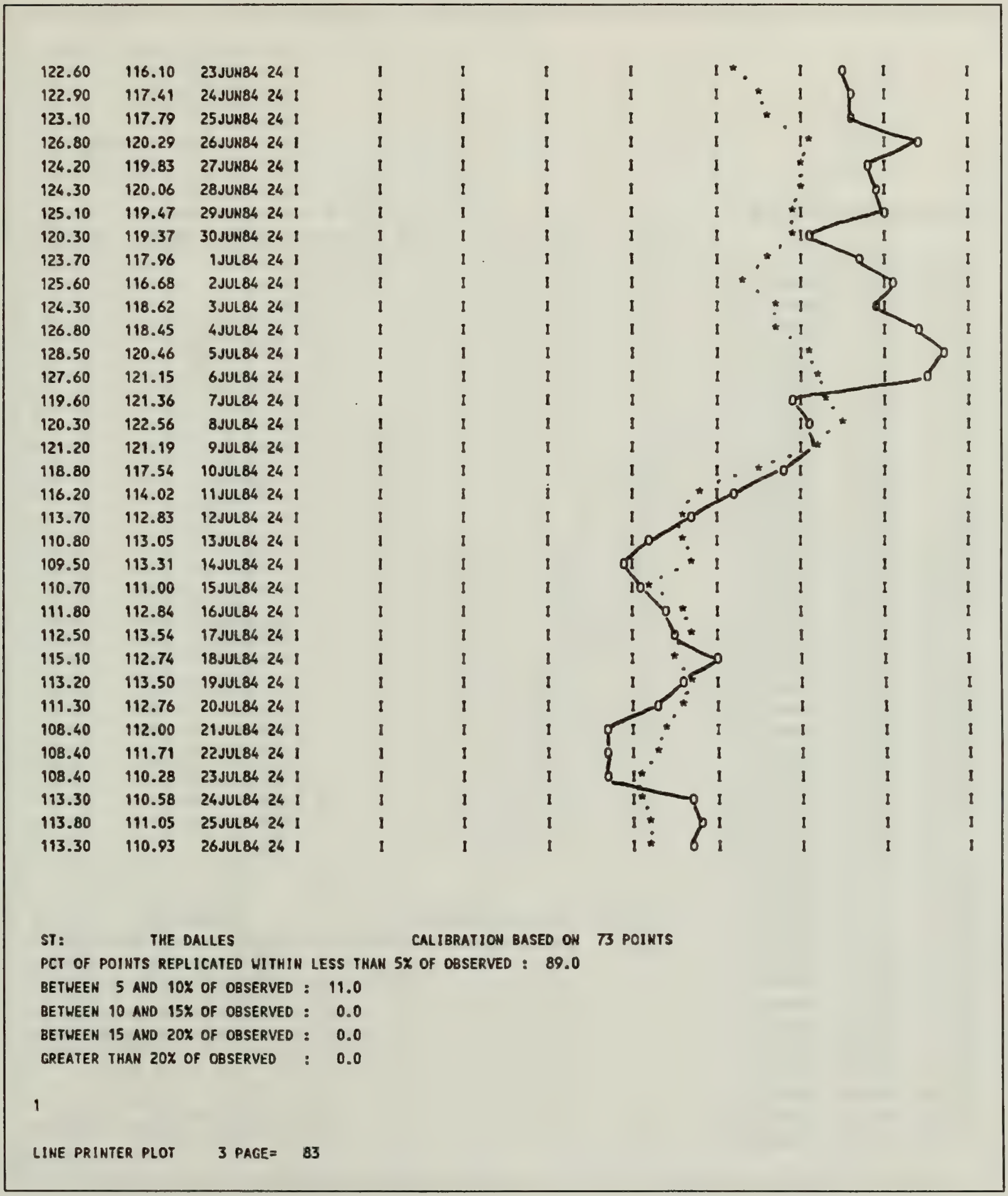
(*) observed=computed, by definition, at headwater sites

## Table I–3. Nitrogen Forebay Saturation Plot - The Dalles



```
                                                              LEGEND:  O=OBSERVED
                                                                       *=COMPUTED

OBSERVED COMPUTED  DATE/TIME                        NITROGEN (% SAT)      (SCALE:  5.00    % PER
                              90.0     95.0     100.0     105.0     110.0     115.0     120.0     125.0     130.0

112.10    109.34   15MAY84 24
114.10    112.18   16MAY84 24
116.10    111.54   17MAY84 24
117.10    112.14   18MAY84 24
118.30    113.11   19MAY84 24
116.70    115.18   20MAY84 24
117.90    115.79   21MAY84 24
118.00    115.95   22MAY84 24
116.30    114.96   23MAY84 24
114.50    115.30   24MAY84 24
116.70    115.16   25MAY84 24
119.00    116.77   26MAY84 24
118.30    117.70   27MAY84 24
121.20    119.06   28MAY84 24
123.00    119.37   29MAY84 24
118.20    119.61   30MAY84 24
116.20    119.59   31MAY84 24
117.50    116.93    1JUN84 24
119.10    116.47    2JUN84 24
121.90    116.02    3JUN84 24
123.70    116.28    4JUN84 24
122.40    116.33    5JUN84 24
122.00    116.54    6JUN84 24
116.60    117.12    7JUN84 24
113.60    117.14    8JUN84 24
114.70    117.24    9JUN84 24
116.10    118.61   10JUN84 24
115.20    118.69   11JUN84 24
117.50    118.11   12JUN84 24
119.00    118.14   13JUN84 24
121.80    117.56   14JUN84 24
120.40    117.96   15JUN84 24
116.30    118.06   16JUN84 24
122.20    116.99   17JUN84 24
123.90    116.53   18JUN84 24
120.90    116.46   19JUN84 24
120.90    116.79   20JUN84 24
120.40    115.34   21JUN84 24
120.50    115.31   22JUN84 24
```

## Table I–3. Nitrogen Forebay Saturation Plot - The Dalles – CONT

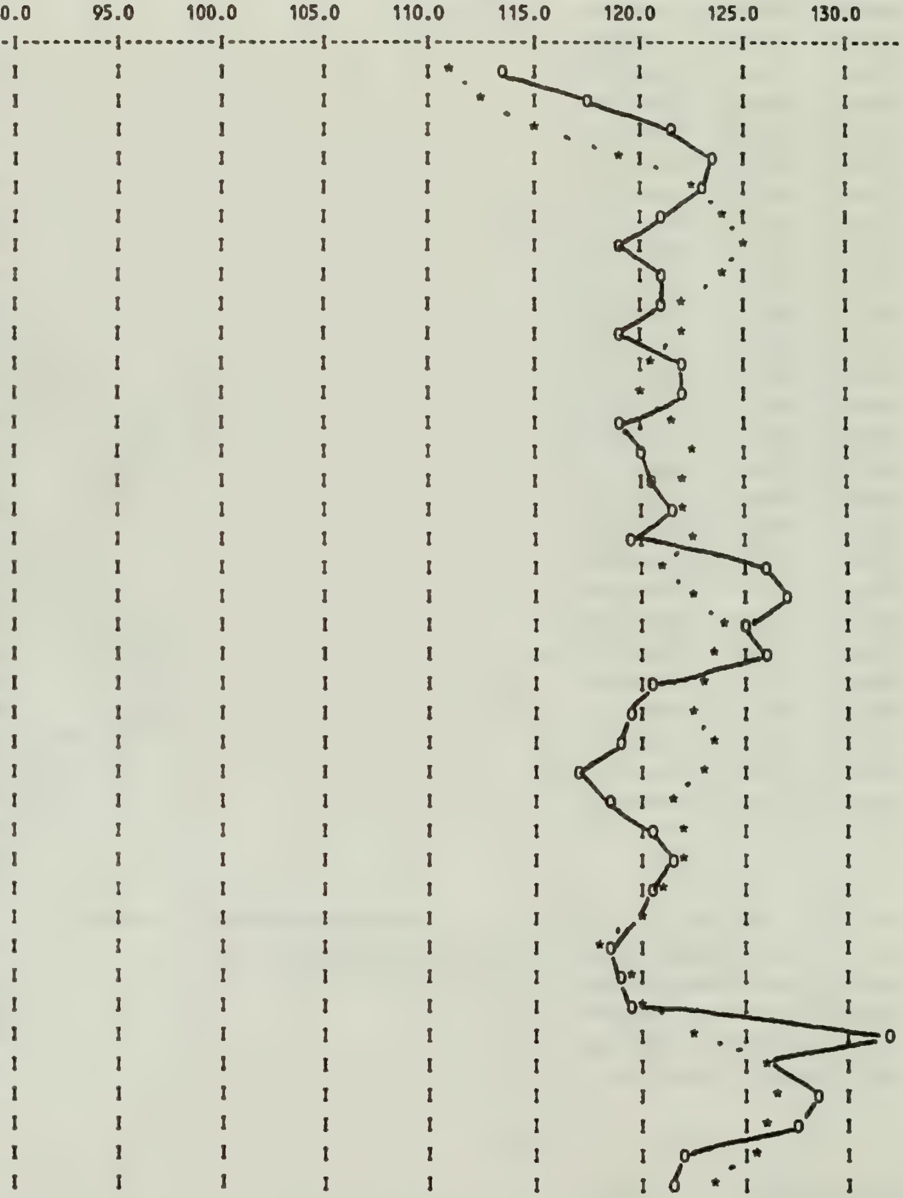


```
122.60    116.10    23JUN84 24
122.90    117.41    24JUN84 24
123.10    117.79    25JUN84 24
126.80    120.29    26JUN84 24
124.20    119.83    27JUN84 24
124.30    120.06    28JUN84 24
125.10    119.47    29JUN84 24
120.30    119.37    30JUN84 24
123.70    117.96     1JUL84 24
125.60    116.68     2JUL84 24
124.30    118.62     3JUL84 24
126.80    118.45     4JUL84 24
128.50    120.46     5JUL84 24
127.60    121.15     6JUL84 24
119.60    121.36     7JUL84 24
120.30    122.56     8JUL84 24
121.20    121.19     9JUL84 24
118.80    117.54    10JUL84 24
116.20    114.02    11JUL84 24
113.70    112.83    12JUL84 24
110.80    113.05    13JUL84 24
109.50    113.31    14JUL84 24
110.70    111.00    15JUL84 24
111.80    112.84    16JUL84 24
112.50    113.54    17JUL84 24
115.10    112.74    18JUL84 24
113.20    113.50    19JUL84 24
111.30    112.76    20JUL84 24
108.40    112.00    21JUL84 24
108.40    111.71    22JUL84 24
108.40    110.28    23JUL84 24
113.30    110.58    24JUL84 24
113.80    111.05    25JUL84 24
113.30    110.93    26JUL84 24


ST:          THE DALLES                      CALIBRATION BASED ON  73 POINTS
PCT OF POINTS REPLICATED WITHIN LESS THAN 5% OF OBSERVED :  89.0
BETWEEN  5 AND 10% OF OBSERVED :  11.0
BETWEEN 10 AND 15% OF OBSERVED :   0.0
BETWEEN 15 AND 20% OF OBSERVED :   0.0
GREATER THAN 20% OF OBSERVED   :   0.0

1

LINE PRINTER PLOT     3 PAGE=   83
```

## Table I–4. Nitrogen Forebay Saturation Plot - Ice Harbor

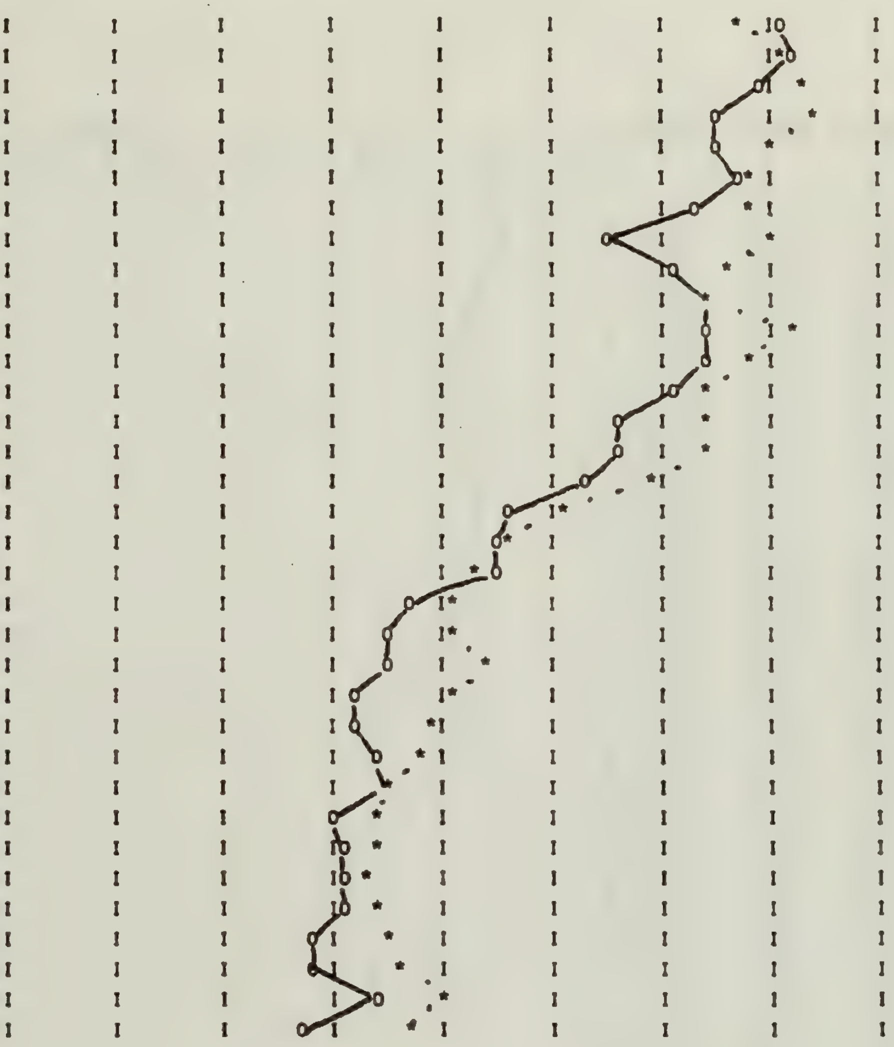
LEGEND: O=OBSERVED
*=COMPUTED

NITROGEN (% SAT) (SCALE: 5.00 % PER



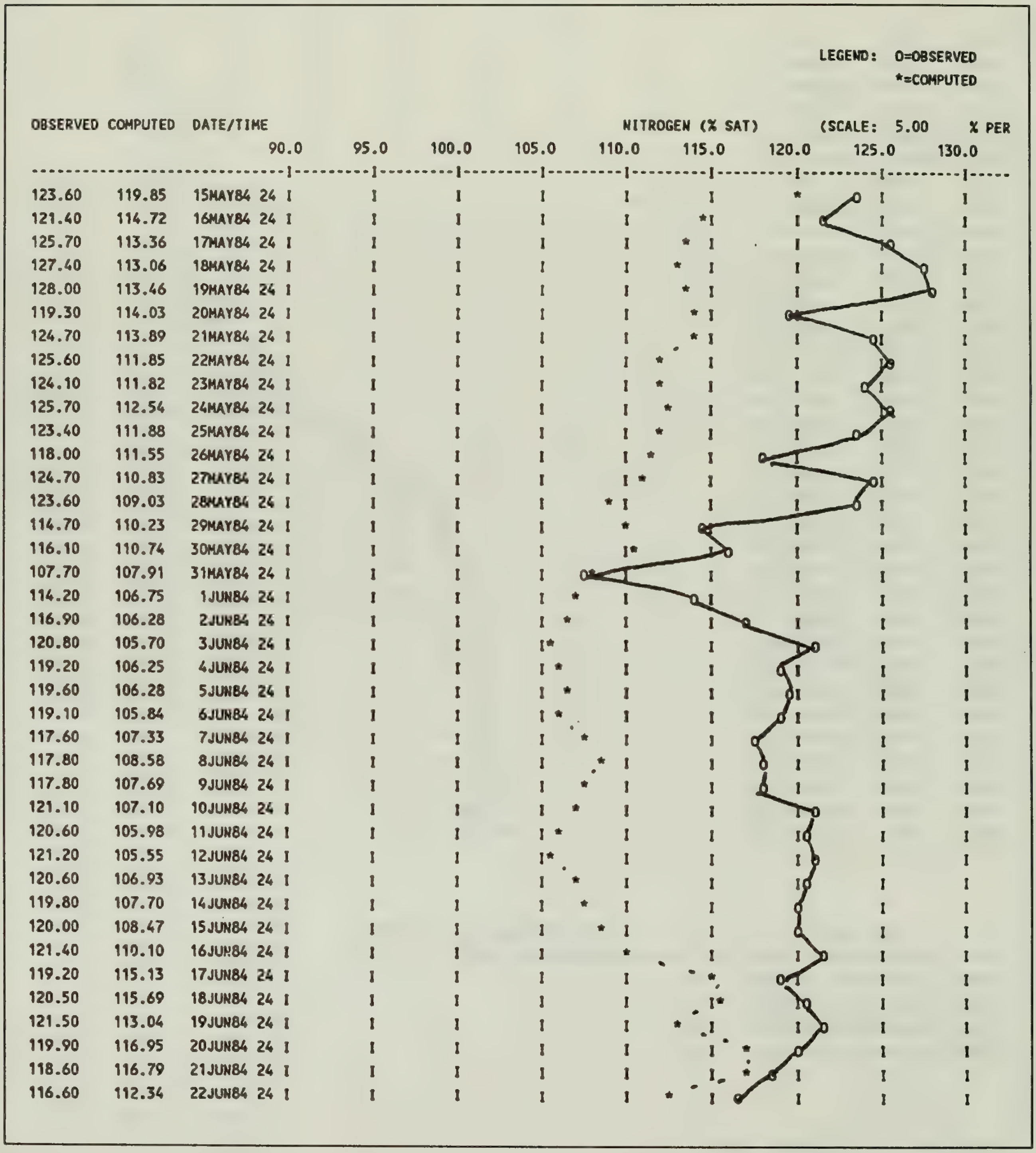
| OBSERVED | COMPUTED | DATE/TIME |
|---|---|---|
| 113.30 | 111.20 | 15MAY84 24 |
| 117.50 | 112.41 | 16MAY84 24 |
| 121.60 | 115.19 | 17MAY84 24 |
| 123.30 | 118.78 | 18MAY84 24 |
| 123.10 | 122.27 | 19MAY84 24 |
| 121.20 | 124.19 | 20MAY84 24 |
| 118.80 | 125.20 | 21MAY84 24 |
| 121.10 | 123.77 | 22MAY84 24 |
| 121.20 | 121.98 | 23MAY84 24 |
| 118.90 | 122.19 | 24MAY84 24 |
| 122.20 | 120.49 | 25MAY84 24 |
| 121.90 | 120.14 | 26MAY84 24 |
| 118.80 | 121.38 | 27MAY84 24 |
| 120.00 | 122.36 | 28MAY84 24 |
| 120.50 | 121.95 | 29MAY84 24 |
| 121.30 | 121.82 | 30MAY84 24 |
| 119.30 | 122.73 | 31MAY84 24 |
| 125.90 | 120.96 | 1JUN84 24 |
| 127.20 | 122.43 | 2JUN84 24 |
| 125.00 | 123.87 | 3JUN84 24 |
| 125.90 | 123.57 | 4JUN84 24 |
| 120.30 | 123.14 | 5JUN84 24 |
| 119.40 | 122.67 | 6JUN84 24 |
| 119.10 | 123.26 | 7JUN84 24 |
| 117.10 | 122.93 | 8JUN84 24 |
| 118.70 | 121.32 | 9JUN84 24 |
| 120.70 | 121.92 | 10JUN84 24 |
| 121.30 | 122.10 | 11JUN84 24 |
| 120.40 | 121.23 | 12JUN84 24 |
| 120.10 | 119.79 | 13JUN84 24 |
| 118.50 | 118.02 | 14JUN84 24 |
| 118.90 | 119.38 | 15JUN84 24 |
| 119.60 | 120.15 | 16JUN84 24 |
| 131.90 | 122.33 | 17JUN84 24 |
| 137.20 | 126.23 | 18JUN84 24 |
| 128.50 | 126.58 | 19JUN84 24 |
| 127.60 | 126.24 | 20JUN84 24 |
| 121.80 | 125.41 | 21JUN84 24 |
| 121.40 | 123.69 | 22JUN84 24 |

## Table I–4. Nitrogen Forebay Saturation Plot - Ice Harbor – CONT



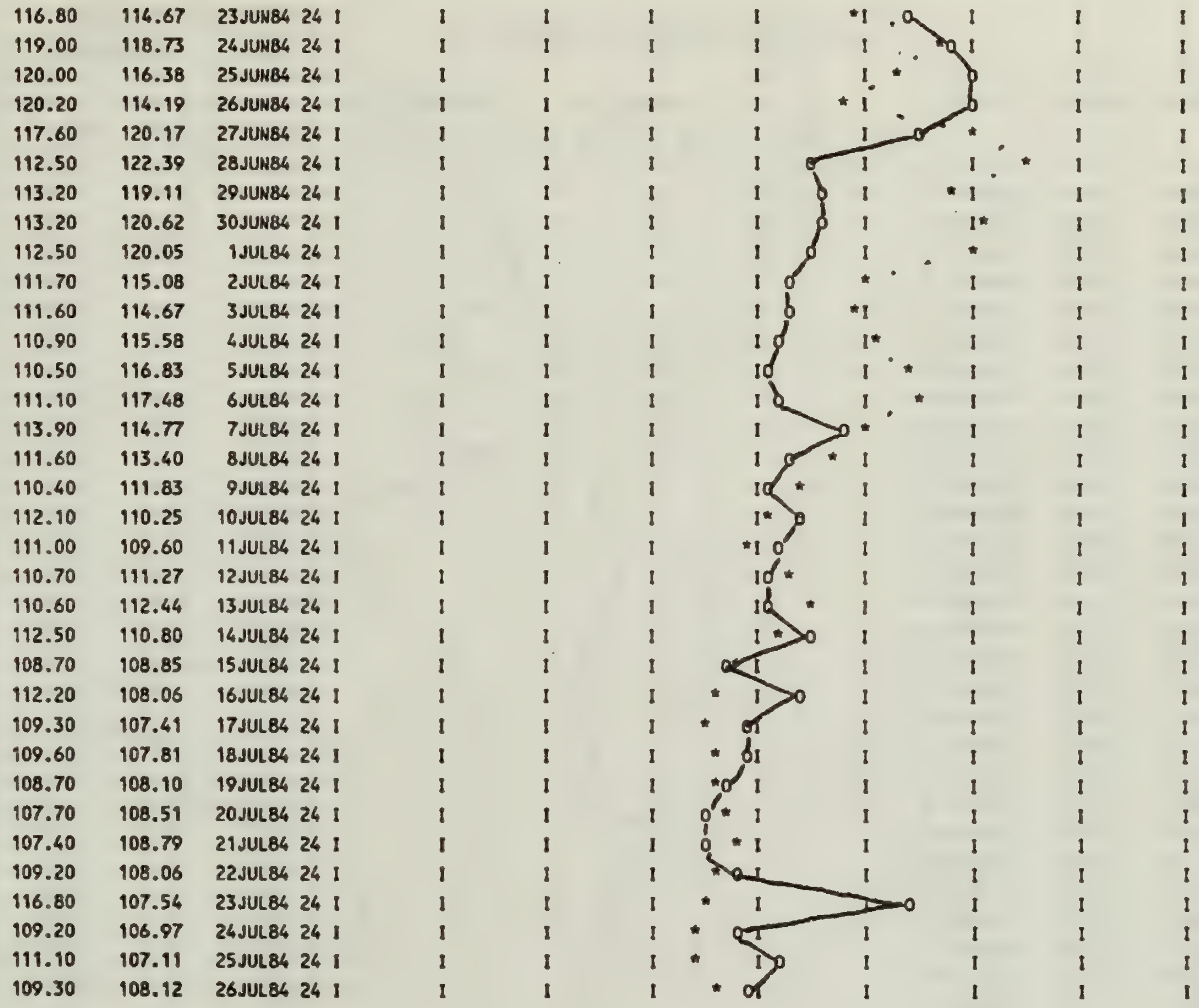
```
125.50    123.52    23JUN84 24
126.00    125.37    24JUN84 24
124.30    126.52    25JUN84 24
122.60    127.07    26JUN84 24
122.70    124.87    27JUN84 24
123.60    124.14    28JUN84 24
121.40    124.15    29JUN84 24
117.40    124.99    30JUN84 24
120.40    122.94     1JUL84 24
122.00    122.18     2JUL84 24
121.90    125.84     3JUL84 24
121.90    123.84     4JUL84 24
120.60    121.87     5JUL84 24
118.10    122.03     6JUL84 24
118.20    121.88     7JUL84 24
116.30    119.38     8JUL84 24
112.90    115.63     9JUL84 24
112.40    113.09    10JUL84 24
112.50    111.43    11JUL84 24
108.50    110.43    12JUL84 24
107.50    110.73    13JUL84 24
107.40    112.21    14JUL84 24
106.00    110.68    15JUL84 24
106.20    109.70    16JUL84 24
107.20    108.97    17JUL84 24
107.40    107.73    18JUL84 24
104.90    107.23    19JUL84 24
105.70    106.77    20JUL84 24
105.30    106.62    21JUL84 24
105.70    107.18    22JUL84 24
104.10    107.27    23JUL84 24
104.00    107.82    24JUL84 24
107.10    110.13    25JUL84 24
103.40    108.56    26JUL84 24


ST:          ICE HARBOR                   CALIBRATION BASED ON  73 POINTS
PCT OF POINTS REPLICATED WITHIN LESS THAN 5% OF OBSERVED :  93.2
BETWEEN  5 AND 10% OF OBSERVED :    6.8
BETWEEN 10 AND 15% OF OBSERVED :    0.0
BETWEEN 15 AND 20% OF OBSERVED :    0.0
GREATER THAN 20% OF OBSERVED   :    0.0

1

LINE PRINTER PLOT     6 PAGE=   86
```

## Table I–5. Nitrogen Forebay Saturation Plot - Priest Rapids



```
                                                              LEGEND:  O=OBSERVED
                                                                       *=COMPUTED

OBSERVED COMPUTED  DATE/TIME                 NITROGEN (% SAT)      (SCALE:  5.00   % PER
                             90.0    95.0   100.0   105.0   110.0   115.0   120.0   125.0   130.0

123.60    119.85   15MAY84 24
121.40    114.72   16MAY84 24
125.70    113.36   17MAY84 24
127.40    113.06   18MAY84 24
128.00    113.46   19MAY84 24
119.30    114.03   20MAY84 24
124.70    113.89   21MAY84 24
125.60    111.85   22MAY84 24
124.10    111.82   23MAY84 24
125.70    112.54   24MAY84 24
123.40    111.88   25MAY84 24
118.00    111.55   26MAY84 24
124.70    110.83   27MAY84 24
123.60    109.03   28MAY84 24
114.70    110.23   29MAY84 24
116.10    110.74   30MAY84 24
107.70    107.91   31MAY84 24
114.20    106.75    1JUN84 24
116.90    106.28    2JUN84 24
120.80    105.70    3JUN84 24
119.20    106.25    4JUN84 24
119.60    106.28    5JUN84 24
119.10    105.84    6JUN84 24
117.60    107.33    7JUN84 24
117.80    108.58    8JUN84 24
117.80    107.69    9JUN84 24
121.10    107.10   10JUN84 24
120.60    105.98   11JUN84 24
121.20    105.55   12JUN84 24
120.60    106.93   13JUN84 24
119.80    107.70   14JUN84 24
120.00    108.47   15JUN84 24
121.40    110.10   16JUN84 24
119.20    115.13   17JUN84 24
120.50    115.69   18JUN84 24
121.50    113.04   19JUN84 24
119.90    116.95   20JUN84 24
118.60    116.79   21JUN84 24
116.60    112.34   22JUN84 24
```

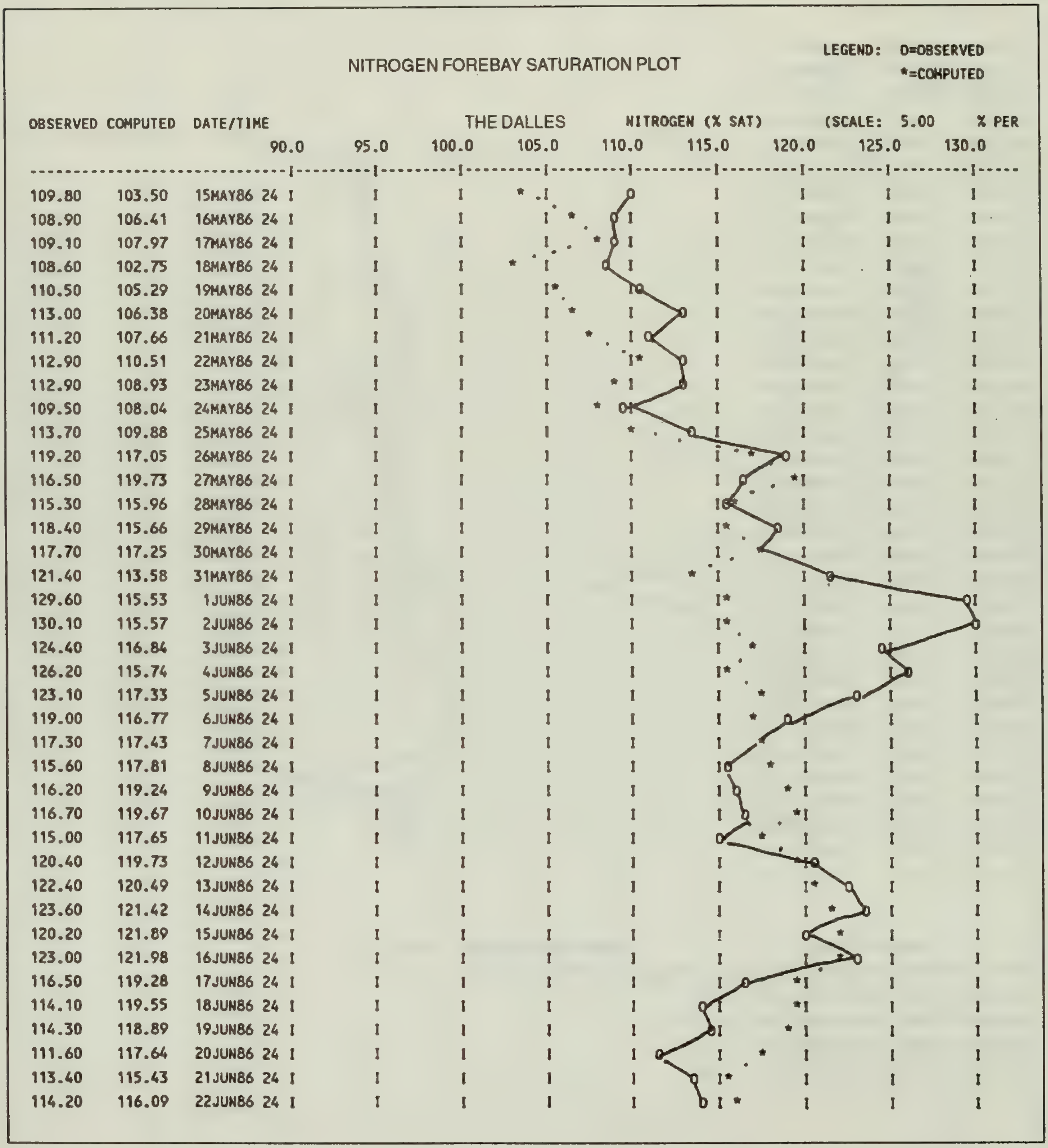
## Table I–5. Nitrogen Forebay Saturation Plot - Priest Rapids – CONT



```
116.80   114.67   23JUN84 24 I
119.00   118.73   24JUN84 24 I
120.00   116.38   25JUN84 24 I
120.20   114.19   26JUN84 24 I
117.60   120.17   27JUN84 24 I
112.50   122.39   28JUN84 24 I
113.20   119.11   29JUN84 24 I
113.20   120.62   30JUN84 24 I
112.50   120.05    1JUL84 24 I
111.70   115.08    2JUL84 24 I
111.60   114.67    3JUL84 24 I
110.90   115.58    4JUL84 24 I
110.50   116.83    5JUL84 24 I
111.10   117.48    6JUL84 24 I
113.90   114.77    7JUL84 24 I
111.60   113.40    8JUL84 24 I
110.40   111.83    9JUL84 24 I
112.10   110.25   10JUL84 24 I
111.00   109.60   11JUL84 24 I
110.70   111.27   12JUL84 24 I
110.60   112.44   13JUL84 24 I
112.50   110.80   14JUL84 24 I
108.70   108.85   15JUL84 24 I
112.20   108.06   16JUL84 24 I
109.30   107.41   17JUL84 24 I
109.60   107.81   18JUL84 24 I
108.70   108.10   19JUL84 24 I
107.70   108.51   20JUL84 24 I
107.40   108.79   21JUL84 24 I
109.20   108.06   22JUL84 24 I
116.80   107.54   23JUL84 24 I
109.20   106.97   24JUL84 24 I
111.10   107.11   25JUL84 24 I
109.30   108.12   26JUL84 24 I
```

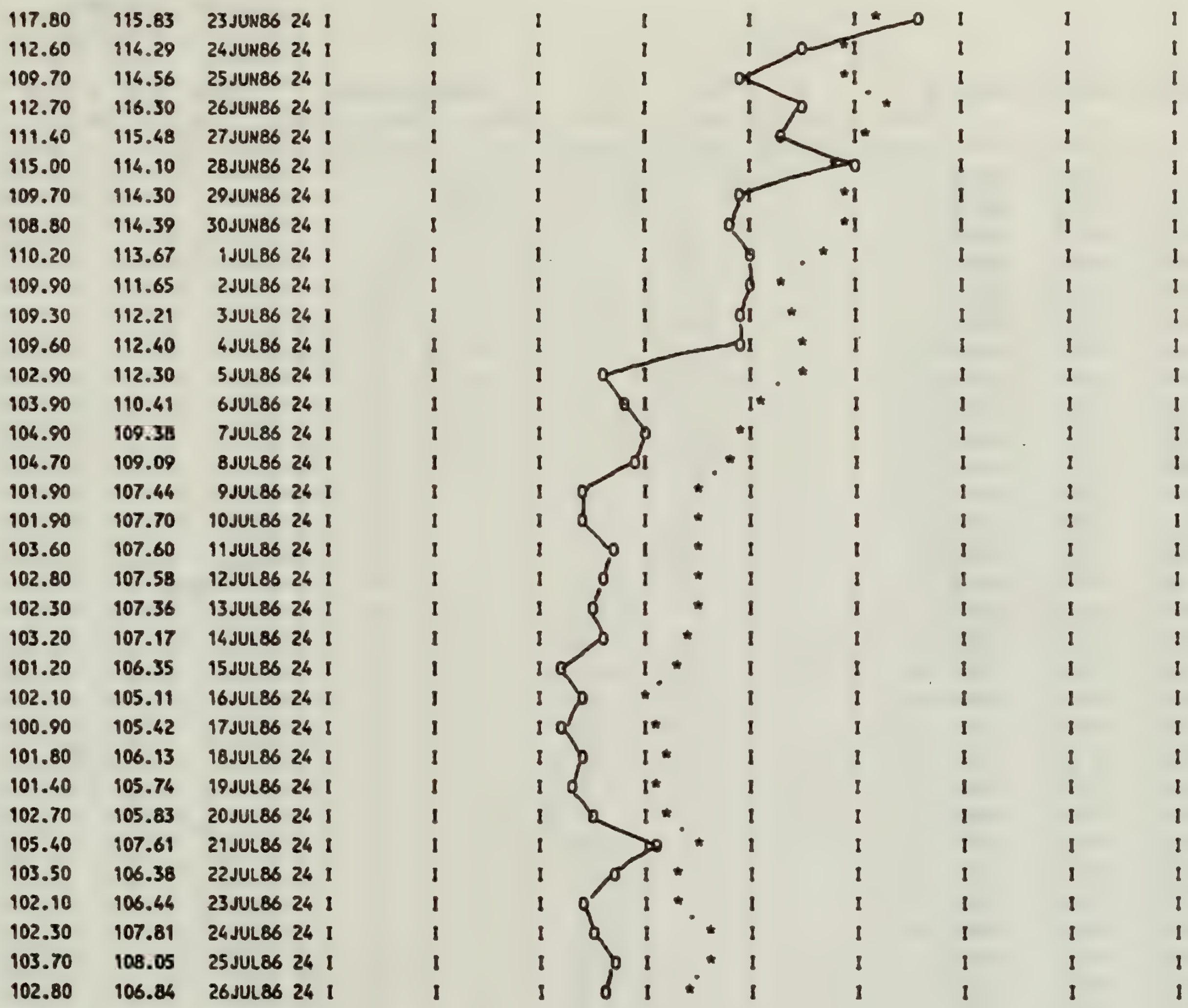
```
 ST:        PRIEST RAPIDS                         CALIBRATION BASED ON  73 POINTS
 PCT OF POINTS REPLICATED WITHIN LESS THAN 5% OF OBSERVED :  50.7
 BETWEEN  5 AND 10% OF OBSERVED :  28.8
 BETWEEN 10 AND 15% OF OBSERVED :  20.5
 BETWEEN 15 AND 20% OF OBSERVED :   0.0
 GREATER THAN 20% OF OBSERVED   :   0.0

1

LINE PRINTER PLOT     10 PAGE=    90
```

## Table I–6. Nitrogen Forebay Saturation Plot - The Dalles



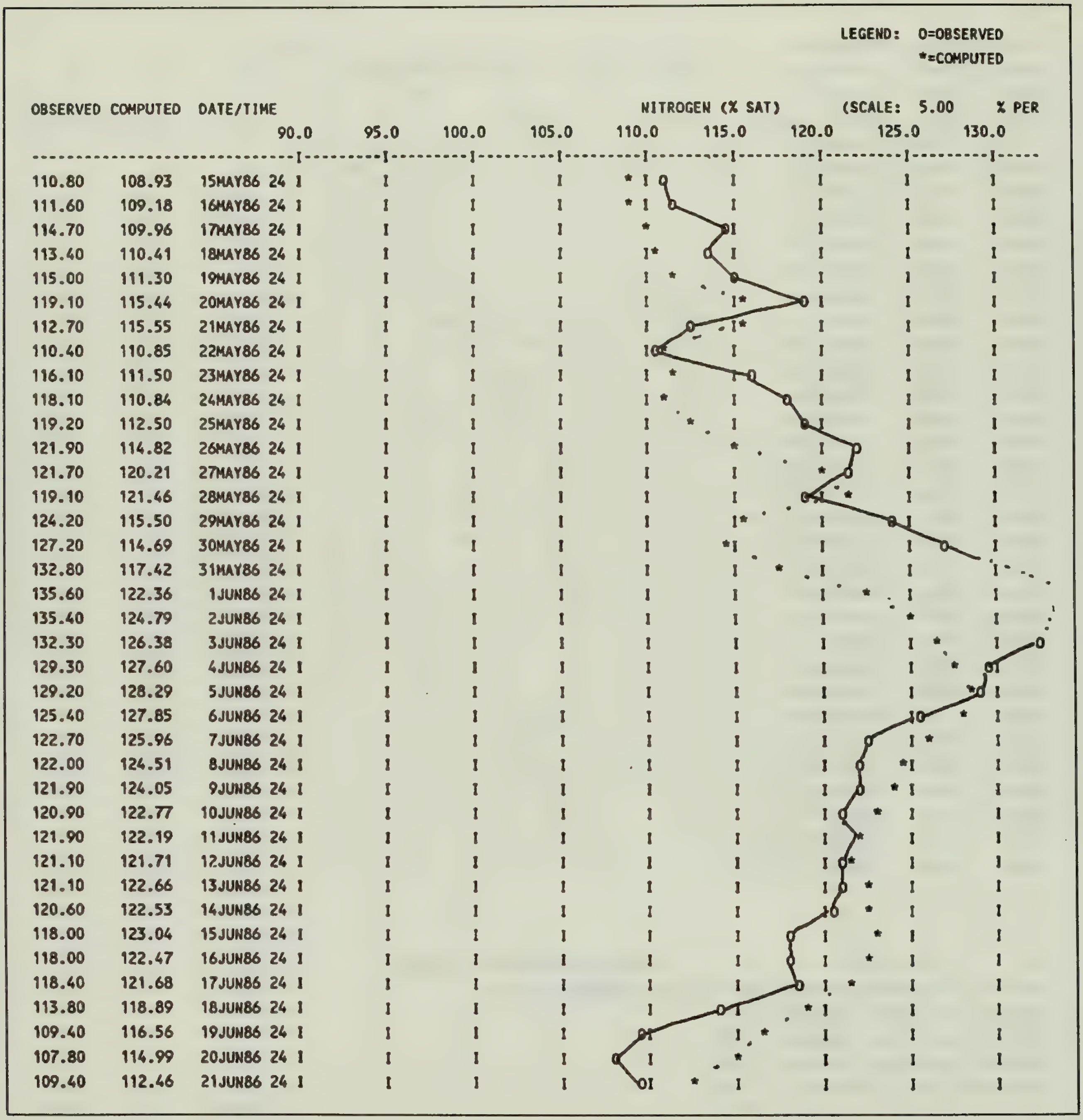
```
                                        NITROGEN FOREBAY SATURATION PLOT                  LEGEND:  O=OBSERVED
                                                                                                   *=COMPUTED

OBSERVED COMPUTED  DATE/TIME                       THE DALLES        NITROGEN (% SAT)        (SCALE:  5.00     % PER
                            90.0      95.0      100.0     105.0     110.0     115.0     120.0     125.0     130.0
----------------------------I---------I---------I---------I---------I---------I---------I---------I---------I-----
109.80    103.50   15MAY86 24
108.90    106.41   16MAY86 24
109.10    107.97   17MAY86 24
108.60    102.75   18MAY86 24
110.50    105.29   19MAY86 24
113.00    106.38   20MAY86 24
111.20    107.66   21MAY86 24
112.90    110.51   22MAY86 24
112.90    108.93   23MAY86 24
109.50    108.04   24MAY86 24
113.70    109.88   25MAY86 24
119.20    117.05   26MAY86 24
116.50    119.73   27MAY86 24
115.30    115.96   28MAY86 24
118.40    115.66   29MAY86 24
117.70    117.25   30MAY86 24
121.40    113.58   31MAY86 24
129.60    115.53    1JUN86 24
130.10    115.57    2JUN86 24
124.40    116.84    3JUN86 24
126.20    115.74    4JUN86 24
123.10    117.33    5JUN86 24
119.00    116.77    6JUN86 24
117.30    117.43    7JUN86 24
115.60    117.81    8JUN86 24
116.20    119.24    9JUN86 24
116.70    119.67   10JUN86 24
115.00    117.65   11JUN86 24
120.40    119.73   12JUN86 24
122.40    120.49   13JUN86 24
123.60    121.42   14JUN86 24
120.20    121.89   15JUN86 24
123.00    121.98   16JUN86 24
116.50    119.28   17JUN86 24
114.10    119.55   18JUN86 24
114.30    118.89   19JUN86 24
111.60    117.64   20JUN86 24
113.40    115.43   21JUN86 24
114.20    116.09   22JUN86 24
```

## Table I–6. Nitrogen Forebay Saturation Plot - The Dalles – CONT



```
117.80   115.83   23JUN86 24
112.60   114.29   24JUN86 24
109.70   114.56   25JUN86 24
112.70   116.30   26JUN86 24
111.40   115.48   27JUN86 24
115.00   114.10   28JUN86 24
109.70   114.30   29JUN86 24
108.80   114.39   30JUN86 24
110.20   113.67    1JUL86 24
109.90   111.65    2JUL86 24
109.30   112.21    3JUL86 24
109.60   112.40    4JUL86 24
102.90   112.30    5JUL86 24
103.90   110.41    6JUL86 24
104.90   109.38    7JUL86 24
104.70   109.09    8JUL86 24
101.90   107.44    9JUL86 24
101.90   107.70   10JUL86 24
103.60   107.60   11JUL86 24
102.80   107.58   12JUL86 24
102.30   107.36   13JUL86 24
103.20   107.17   14JUL86 24
101.20   106.35   15JUL86 24
102.10   105.11   16JUL86 24
100.90   105.42   17JUL86 24
101.80   106.13   18JUL86 24
101.40   105.74   19JUL86 24
102.70   105.83   20JUL86 24
105.40   107.61   21JUL86 24
103.50   106.38   22JUL86 24
102.10   106.44   23JUL86 24
102.30   107.81   24JUL86 24
103.70   108.05   25JUL86 24
102.80   106.84   26JUL86 24

ST:         THE DALLES                   CALIBRATION BASED ON  73 POINTS
PCT OF POINTS REPLICATED WITHIN LESS THAN 5% OF OBSERVED :  78.1
BETWEEN  5 AND 10% OF OBSERVED :  19.2
BETWEEN 10 AND 15% OF OBSERVED :   2.7
BETWEEN 15 AND 20% OF OBSERVED :   0.0
GREATER THAN 20% OF OBSERVED   :   0.0

1

LINE PRINTER PLOT     3 PAGE=   83
```

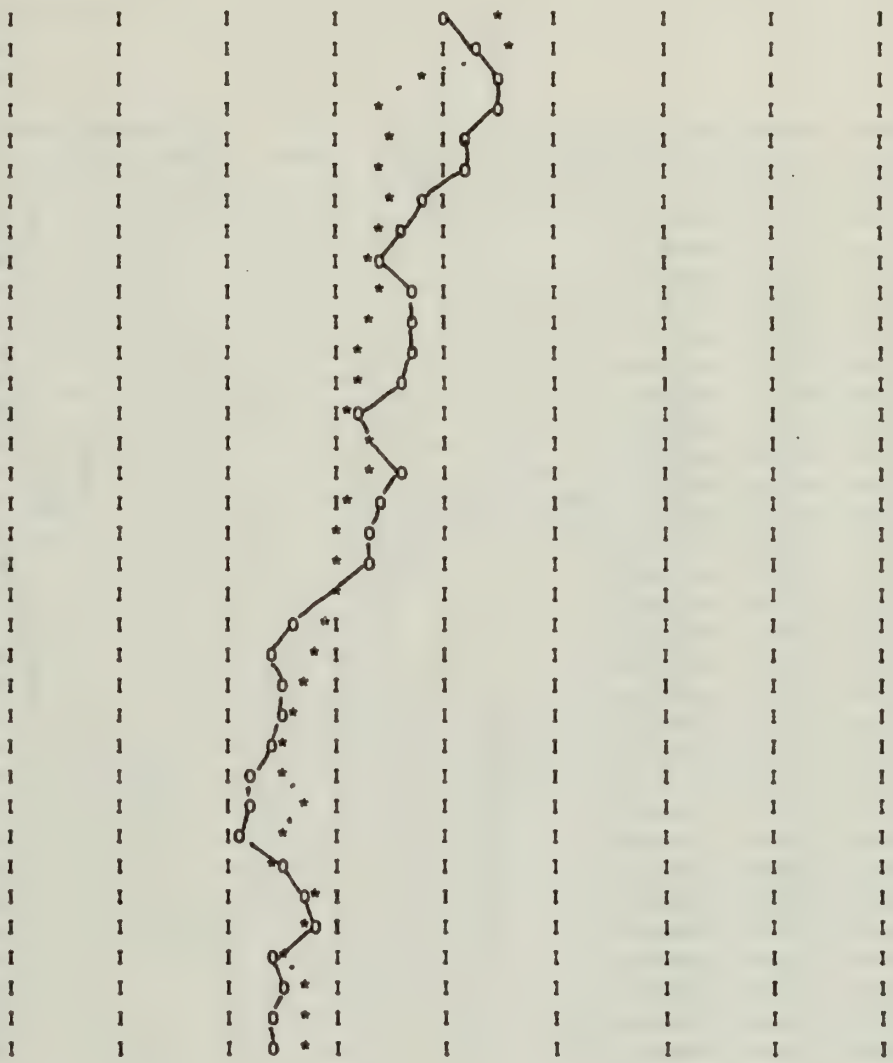
## Table I–7. Nitrogen Forebay Saturation Plot - Ice Harbor



```
                                                                            LEGEND:  O=OBSERVED
                                                                                     *=COMPUTED

OBSERVED COMPUTED  DATE/TIME                                      NITROGEN (% SAT)       (SCALE:  5.00     % PER
                               90.0     95.0     100.0     105.0     110.0     115.0     120.0     125.0     130.0

110.80    108.93   15MAY86 24
111.60    109.18   16MAY86 24
114.70    109.96   17MAY86 24
113.40    110.41   18MAY86 24
115.00    111.30   19MAY86 24
119.10    115.44   20MAY86 24
112.70    115.55   21MAY86 24
110.40    110.85   22MAY86 24
116.10    111.50   23MAY86 24
118.10    110.84   24MAY86 24
119.20    112.50   25MAY86 24
121.90    114.82   26MAY86 24
121.70    120.21   27MAY86 24
119.10    121.46   28MAY86 24
124.20    115.50   29MAY86 24
127.20    114.69   30MAY86 24
132.80    117.42   31MAY86 24
135.60    122.36    1JUN86 24
135.40    124.79    2JUN86 24
132.30    126.38    3JUN86 24
129.30    127.60    4JUN86 24
129.20    128.29    5JUN86 24
125.40    127.85    6JUN86 24
122.70    125.96    7JUN86 24
122.00    124.51    8JUN86 24
121.90    124.05    9JUN86 24
120.90    122.77   10JUN86 24
121.90    122.19   11JUN86 24
121.10    121.71   12JUN86 24
121.10    122.66   13JUN86 24
120.60    122.53   14JUN86 24
118.00    123.04   15JUN86 24
118.00    122.47   16JUN86 24
118.40    121.68   17JUN86 24
113.80    118.89   18JUN86 24
109.40    116.56   19JUN86 24
107.80    114.99   20JUN86 24
109.40    112.46   21JUN86 24
```

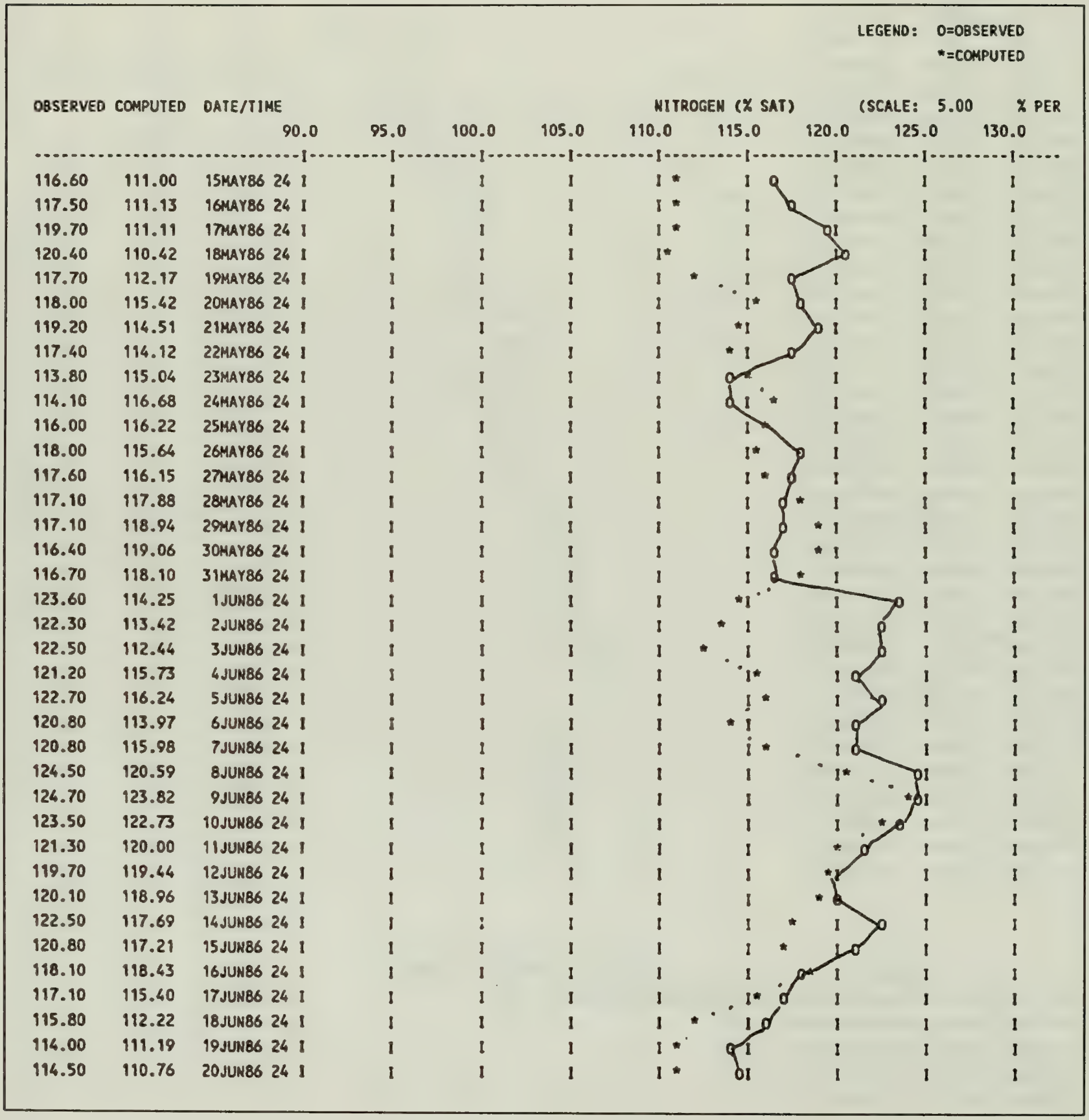
## Table I–7. Nitrogen Forebay Saturation Plot - Ice Harbor – CONT

```
110.20     112.62    22JUN86 24 I
111.40     112.97    23JUN86 24 I
112.30     109.20    24JUN86 24 I
112.30     107.02    25JUN86 24 I
111.00     107.49    26JUN86 24 I
110.80     107.10    27JUN86 24 I
109.20     107.74    28JUN86 24 I
108.00     106.98    29JUN86 24 I
107.20     106.39    30JUN86 24 I
108.60     107.06     1JUL86 24 I
108.60     106.53     2JUL86 24 I
108.40     106.19     3JUL86 24 I
108.20     106.20     4JUL86 24 I
106.20     105.67     5JUL86 24 I
106.30     106.33     6JUL86 24 I
108.20     106.73     7JUL86 24 I
107.10     105.72     8JUL86 24 I
106.60     105.07     9JUL86 24 I
106.50     104.97    10JUL86 24 I
104.80     104.92    11JUL86 24 I
103.20     104.26    12JUL86 24 I
101.90     103.82    13JUL86 24 I
102.70     103.36    14JUL86 24 I
102.60     103.05    15JUL86 24 I
101.90     102.54    16JUL86 24 I
101.00     102.56    17JUL86 24 I
101.20     103.37    18JUL86 24 I
100.40     102.49    19JUL86 24 I
102.50     101.87    20JUL86 24 I
103.70     103.77    21JUL86 24 I
104.00     103.45    22JUL86 24 I
102.10     102.64    23JUL86 24 I
102.40     103.45    24JUL86 24 I
102.00     103.42    25JUL86 24 I
101.80     103.57    26JUL86 24 I
```



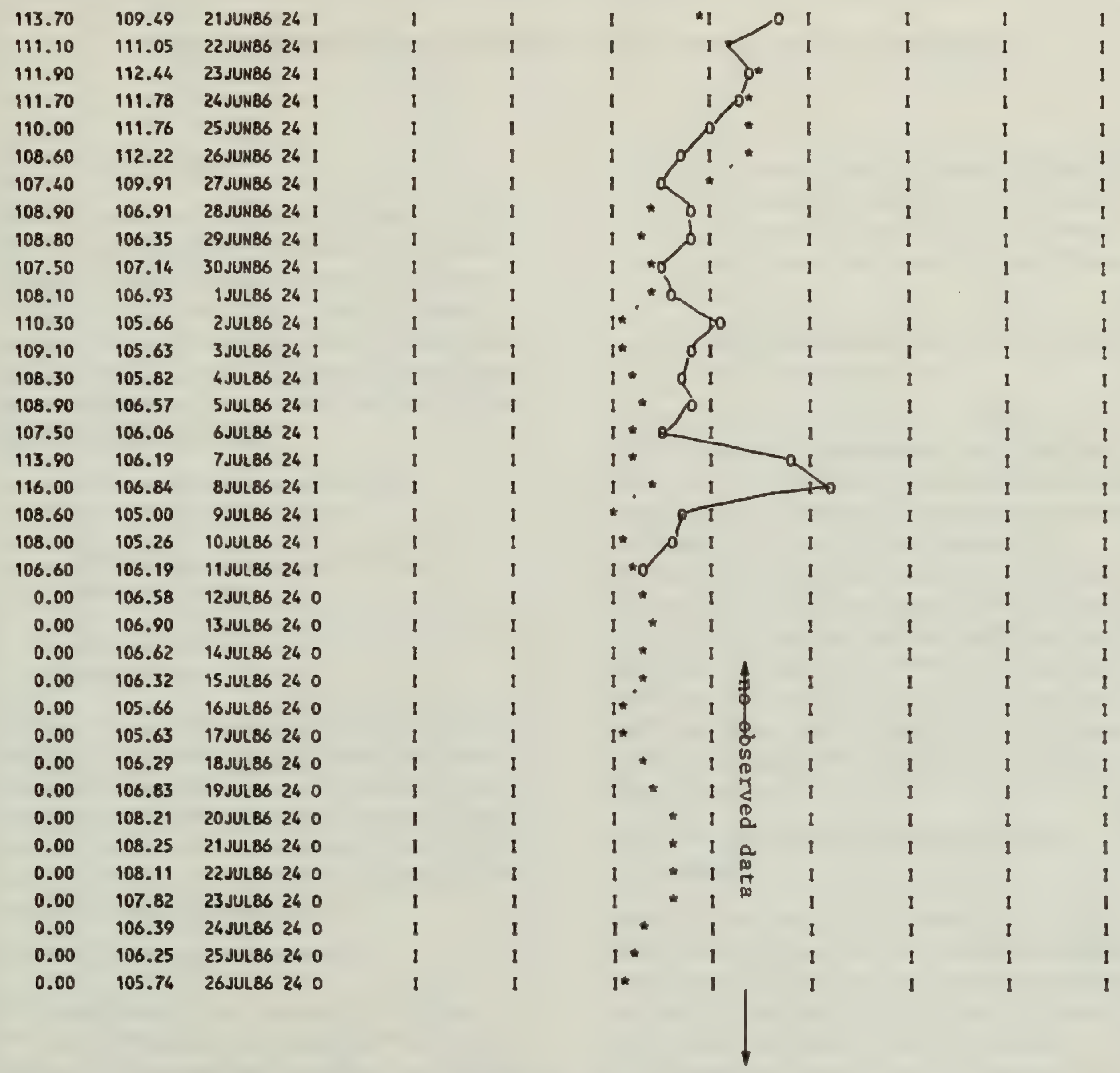
```
ST:          ICE HARBOR                    CALIBRATION BASED ON  73 POINTS
PCT OF POINTS REPLICATED WITHIN LESS THAN 5% OF OBSERVED :  86.3
BETWEEN  5 AND 10% OF OBSERVED :  12.3
BETWEEN 10 AND 15% OF OBSERVED :   1.4
BETWEEN 15 AND 20% OF OBSERVED :   0.0
GREATER THAN 20% OF OBSERVED   :   0.0

1

LINE PRINTER PLOT     6 PAGE=   86
```

## Table I–8. Nitrogen Forebay Saturation Plot - Priest Rapids



```
                                                                                      LEGEND:  O=OBSERVED
                                                                                               *=COMPUTED

OBSERVED COMPUTED  DATE/TIME                                       NITROGEN (% SAT)      (SCALE:  5.00     % PER
                                90.0     95.0     100.0     105.0     110.0     115.0     120.0     125.0     130.0
-------------------------------I---------I---------I---------I---------I---------I---------I---------I---------I-----
116.60     111.00     15MAY86 24
117.50     111.13     16MAY86 24
119.70     111.11     17MAY86 24
120.40     110.42     18MAY86 24
117.70     112.17     19MAY86 24
118.00     115.42     20MAY86 24
119.20     114.51     21MAY86 24
117.40     114.12     22MAY86 24
113.80     115.04     23MAY86 24
114.10     116.68     24MAY86 24
116.00     116.22     25MAY86 24
118.00     115.64     26MAY86 24
117.60     116.15     27MAY86 24
117.10     117.88     28MAY86 24
117.10     118.94     29MAY86 24
116.40     119.06     30MAY86 24
116.70     118.10     31MAY86 24
123.60     114.25      1JUN86 24
122.30     113.42      2JUN86 24
122.50     112.44      3JUN86 24
121.20     115.73      4JUN86 24
122.70     116.24      5JUN86 24
120.80     113.97      6JUN86 24
120.80     115.98      7JUN86 24
124.50     120.59      8JUN86 24
124.70     123.82      9JUN86 24
123.50     122.73     10JUN86 24
121.30     120.00     11JUN86 24
119.70     119.44     12JUN86 24
120.10     118.96     13JUN86 24
122.50     117.69     14JUN86 24
120.80     117.21     15JUN86 24
118.10     118.43     16JUN86 24
117.10     115.40     17JUN86 24
115.80     112.22     18JUN86 24
114.00     111.19     19JUN86 24
114.50     110.76     20JUN86 24
```

## Table I–8. Nitrogen Forebay Saturation Plot - Priest Rapids – CONT



```
113.70    109.49   21JUN86 24 I         I         I         I        *I      O  I         I         I         I
111.10    111.05   22JUN86 24 I         I         I         I         I *       I         I         I         I
111.90    112.44   23JUN86 24 I         I         I         I         I   O*    I         I         I         I
111.70    111.78   24JUN86 24 I         I         I         I         I  O*     I         I         I         I
110.00    111.76   25JUN86 24 I         I         I         I         O   *     I         I         I         I
108.60    112.22   26JUN86 24 I         I         I         I      O  I   *     I         I         I         I
107.40    109.91   27JUN86 24 I         I         I         I    O    *         I         I         I         I
108.90    106.91   28JUN86 24 I         I         I         I   *   O I         I         I         I         I
108.80    106.35   29JUN86 24 I         I         I         I  *    O I         I         I         I         I
107.50    107.14   30JUN86 24 I         I         I         I   *O    I         I         I         I         I
108.10    106.93    1JUL86 24 I         I         I         I   * O   I         I         I         I         I
110.30    105.66    2JUL86 24 I         I         I         I*        IO        I         I         I         I
109.10    105.63    3JUL86 24 I         I         I         I*      O I         I         I         I         I
108.30    105.82    4JUL86 24 I         I         I         I *    O  I         I         I         I         I
108.90    106.57    5JUL86 24 I         I         I         I  *    O I         I         I         I         I
107.50    106.06    6JUL86 24 I         I         I         I *  O    I         I         I         I         I
113.90    106.19    7JUL86 24 I         I         I         I *       I       O I         I         I         I
116.00    106.84    8JUL86 24 I         I         I         I   *     I         I O       I         I         I
108.60    105.00    9JUL86 24 I         I         I         *      O  I         I         I         I         I
108.00    105.26   10JUL86 24 I         I         I         I*    O   I         I         I         I         I
106.60    106.19   11JUL86 24 I         I         I         I *O      I         I         I         I         I
  0.00    106.58   12JUL86 24 O         I         I         I  *      I         I         I         I         I
  0.00    106.90   13JUL86 24 O         I         I         I   *     I         I         I         I         I
  0.00    106.62   14JUL86 24 O         I         I         I  *      I         I         I         I         I
  0.00    106.32   15JUL86 24 O         I         I         I  *      I         I         I         I         I
  0.00    105.66   16JUL86 24 O         I         I         I*        I         I         I         I         I
  0.00    105.63   17JUL86 24 O         I         I         I*        I         I         I         I         I
  0.00    106.29   18JUL86 24 O         I         I         I  *      I         I         I         I         I
  0.00    106.83   19JUL86 24 O         I         I         I   *     I         I         I         I         I
  0.00    108.21   20JUL86 24 O         I         I         I     *   I         I         I         I         I
  0.00    108.25   21JUL86 24 O         I         I         I     *   I         I         I         I         I
  0.00    108.11   22JUL86 24 O         I         I         I     *   I         I         I         I         I
  0.00    107.82   23JUL86 24 O         I         I         I     *   I         I         I         I         I
  0.00    106.39   24JUL86 24 O         I         I         I  *      I         I         I         I         I
  0.00    106.25   25JUL86 24 O         I         I         I *       I         I         I         I         I
  0.00    105.74   26JUL86 24 O         I         I         I*        I         I         I         I         I


ST:        PRIEST RAPIDS                    CALIBRATION BASED ON  58 POINTS
PCT OF POINTS REPLICATED WITHIN LESS THAN 5% OF OBSERVED :  82.8
BETWEEN  5 AND 10% OF OBSERVED :  17.2
BETWEEN 10 AND 15% OF OBSERVED :   0.0
BETWEEN 15 AND 20% OF OBSERVED :   0.0
GREATER THAN 20% OF OBSERVED   :   0.0

1

LINE PRINTER PLOT     10 PAGE=    90
```

## TECHNICAL EXHIBIT J

## SEDIMENT MODELING WITH THE ENHANCED HEC–5Q MODEL

### J–1 INTRODUCTION

This document describes full–scale water quality model simulations of the Columbia–Snake River system for several proposed operation strategies, including existing operations. Ebasco provided technical support to the U.S. Army Corps of Engineers (Corps) as part of the Columbia River System Operation Review (SOR). There were three objectives to the modeling study:

- Select and prioritize water quality parameters to be evaluated.
- Build a full–scale numerical model using HEC–5Q.
- Quantify a sub–set of the selected parameters.

The data sources, conceptual model, numerical modeling procedures, model boundary and initial conditions, and a summary of the results are described in this report. Examples of model output are presented to show the water quality effects of alternative operations and the relative significance of the modeled water quality parameters.

### J–2 STUDY AREA AND PERIOD

The modeled study area includes the Columbia River from International Boundary with Canada to Benneville Dam, and the Snake River from the head of Brownlee Reservoir to the Snake River's confluence with the Columbia. A schematic diagram of the modeled river system appears in Figure J–1. The system has four main branches:

- Dworshak (North Fork of the Clearwater River, downstream to the mouth of the Clearwater River);
- Hells Canyon (Snake River upstream of the confluence with the Clearwater River);
- Lower Snake, from confluence of Clearwater to confluence of Snake River with Columbia River); and Columbia River, from Grand Coulee Dam to confluence of Snake River; and
- Lower Columbia; from confluence of Snake River to Bonneville Dam.

The base period for the SOR study extends from 1974 through 1992. Water quality data from this period were used to describe existing conditions and to predict future conditions. To project environmental impacts for 20 years into the future, NEPA requires EISs, such as this SOR study. The SOR's 20–year projection period starts in 1995. Ebasco identified and collected data from published water quality measurements taken within the study area during the base period to provide a basis for water quality parameter selection and prioritization, and for full–scale model simulations of current and future conditions.

### J–3 THE FULL–SCALE WATER QUALITY MODEL

The HEC–5Q program was selected by the SOR Water Quality Work Group to model water quality in the Columbia River system. A HEC–5Q model was partially built prior to this contract by Resource Management Associates (RMA). The model, "COLTEMP," was built primarily to address water temperature issues. Conventional water quality parameters were included in COLTEMP, but their evaluation was not emphasized. The Corps specified that the model's current set of water quality input data be refined, and expanded to include toxic pollutants such as organics, heavy metals, and dioxin. In addition, the Corps placed high priority on sediment evaluation. The Corps' Walla Walla District Hydrology Branch conducted its own sediment transport model study using the HEC–6 model

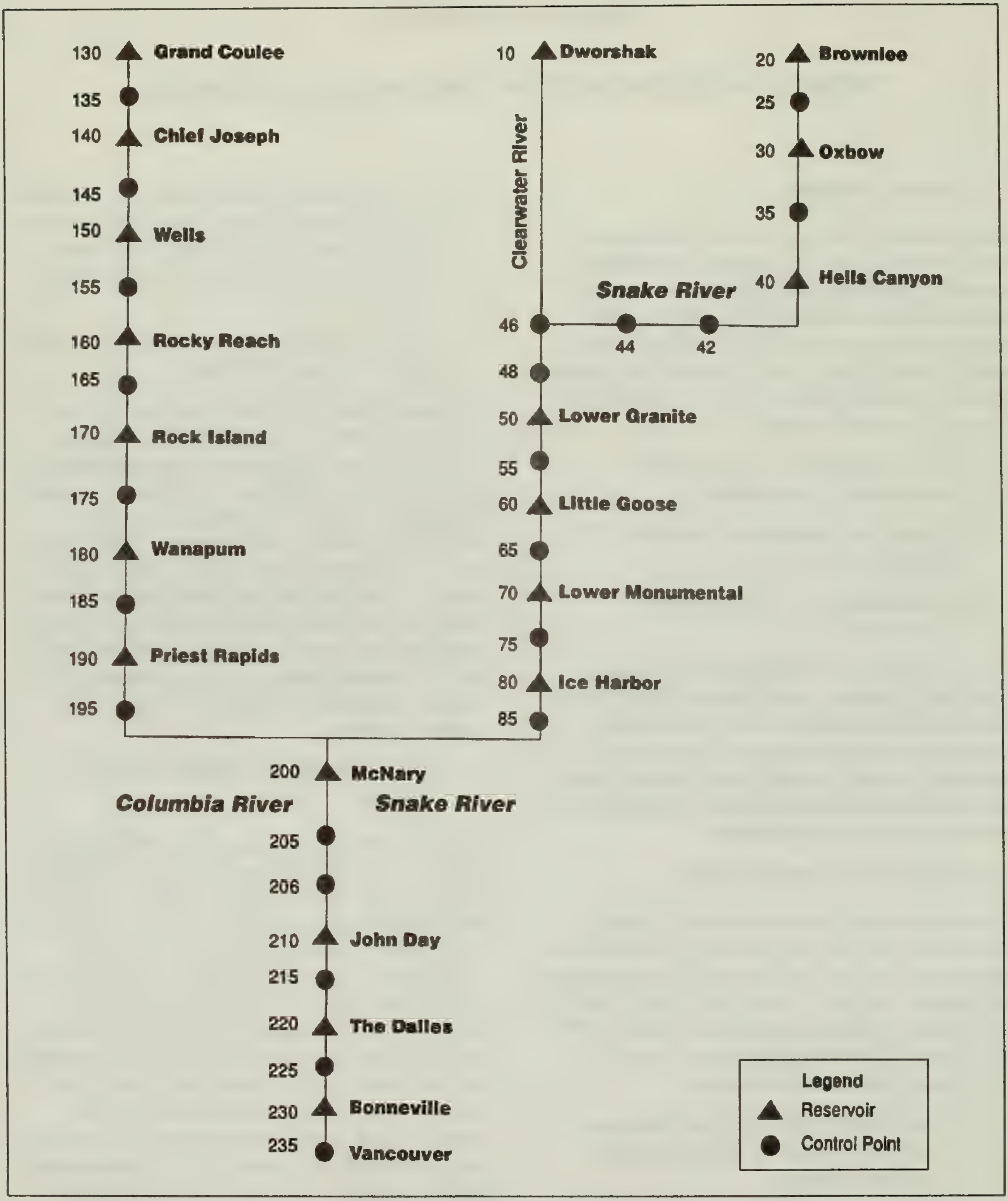


Figure J–1. Schematic Diagram of HEC–5Q Model of Columbia–Snake River System to provide sediment inputs to the new "enhanced" HEC–5Q model.

The Corps specified that the HEC–5Q model provide quantitative water quality information at one station within each major trunk of the river system and at other significant points where the greatest impacts were expected. Time series data were output from the HEC–5Q model at the John Day Dam forebay (lower Columbia), Priest Rapids Dam forebay (upper Columbia), Ice Harbor Dam forebay (lower Snake), and at Lower Granite Dam forebay (high–sediment impact station). The station time series output data provided value measures for alternative comparisons. The value measure specified by the Corps is the frequency of water quality standard exceedences determined by the HEC–5Q model output for these four stations.

## J–4 MODEL APPLICATION LIMITS

It is important to note that the data, procedures and models were selected to serve the specific purposes of this planning study. One of the main objectives of the SOR is to select a system operations plan by comparing the merits and impacts of proposed alternative operations on a system–wide basis. Models applied for these types of large–scale planning studies require less detail and rigor in their applications than is needed for a facility design task, for example. However, the SOR project required that the quantitative analysis be as accurate as possible, and to provide absolute quantities for the planning process.

The accuracy of the water quality data and physical property quantification, and thus the model results, are limited due to both a lack of comprehensive water quality monitoring throughout the system and the large geographic scope of the study. Also, this model study developed new procedures that advanced the state of water quality technology; but there is not yet enough existing data to thoroughly verify the results. Thus the SOR project accuracy objectives could not be strictly followed. This model study resorted to all known and appropriate data and technology available to determine the effect of system operations on the distribution of pollutants within the mainstem Columbia and lower Snake Rivers.

For the purposes of SOR comparative full–scale water quality modeling studies, all alternatives involving no reservoir drawdown (e.g. 1, 2, 3, etc.) are grouped together in a class that is represented by alternative 2a. In this context, results pertaining to alternative 2a will often be referred to as base case results.

## J–5 PROPOSED SOR OPERATION STRATEGIES

Over 90 different system operation alternatives were originally proposed early in the SOR process. The SOR Work Groups performed a preliminary analysis to screen out the less feasible alternatives. The remaining alternatives were grouped into seven system operation strategies (SOSs). The final SOS alternatives, described in more detail in Chapter 4 of this Water Quality Appendix, included the following:

### SOS 1 – Pre – ESA Operation

Columbia River system operations before changes were made as a result of the ESA listing of three Snake River salmon stocks.

### SOS 2 – Current Operations

Current (1992) operation of the Columbia River system with interim flow improvement measures made in response to ESA listings of Snake River salmon; most closely represents the draft recommendations issued by NMFS Snake River Salmon Recovery Team in October 1993.

### SOS 3 – Flow Augmentation

Provide more water to move fish down the river by setting flow targets for every month.

### SOS 4 – Stable Storage Project Operation

Operate the storage reservoirs to benefit recreation, resident fish, wildlife, and anadromous fish, while minimizing impacts of such operation to power and flood control.

**SOS 5 – Natural River Operation**

Aid anadromous fish by drawing down the four lower Snake River projects to streambed levels.

**SOS 6 – Fixed Drawdown**

Aid anadromous fish by drawing down the four lower Snake River projects to fixed elevations below minimum operating pool.

**SOS 7 – Federal Resource Agency Operations**

Incorporates the operations suggested by the USFWS and NMFS as cooperating agencies.

## J–6 CONCEPTUAL MODEL

Water quality issues are presented in a conceptual model by describing the physical, chemical and biological phenomena observed in a water system, the measurable parameters, the monitoring network, naturally occurring external stresses on the system, the human activities that influence water quality, and the resulting state of the system both internally and at its boundary. The conceptual water quality model of the Columbia River system presented in this report describes only the more important environmental mechanisms and reservoir operations and how they are represented in the full–scale numerical model. HEC–5Q and HEC–6 are the two models used for full–scale water quality modeling. The Corps' Hydrologic Engineering Center (HEC) developed these programs. Their underlying processes are described in the HEC–5Q (Corps, 1986), and HEC–6 (Corps, 1991a) manuals. The key aspects of these conceptual models, as applied to the Columbia River system, are presented here. How these model processes are appropriate to simulate the Columbia River system conceptual model is discussed below.

## J–7 SIMULATION PERIOD

The time frame of the conceptual water quality model was selected to adequately predict long–term cumulative effects that the proposed operations may produce. The only water quality parameter that could cause a long–term cumulative effect is sediment. Sediment is stored in the system and doesn't completely flow through the system within a year, unlike other water quality parameters. Long–term sediment impacts had to be evaluated, but a daily time–step was also needed to produce results of adequate short–term resolution. An abbreviated simulation period was selected to avoid simulating 20 years at daily time steps. It was assumed that five years would be required for the system to reach a new dynamic sediment transport equilibrium and that, once this equilibrium was reached, further cumulative impacts would be negligible. Therefore, a five–year simulation period was used in this study.

## J–8 PHYSICAL, CHEMICAL, AND BIOLOGICAL PROCESSES

The natural phenomena observed in a river ecosystem that affect water quality are physical, chemical and biological mechanisms. These are the foundations of the conceptual model. Important physical mechanisms include water and heat inputs; transport; light and gas transfer between the atmosphere and a water body; the erosion of reservoir banks, scouring of sediments from the channel beds; and settling of solids in the water column. The chemical mechanisms include solution equilibriums, reaction kinetics, and carbonate equilibriums of natural waters. Biologic mechanisms include organic matter, nutrient cycles, phytoplankton growth kinetics, photosynthesis, and biochemical oxygen demand. The most influential parameters to water quality that are measurable attributes of the phenomena observed in the Columbia River system are described in the following sections.

### J–8.1 Hydrology

The evaluation of the system's hydrology is basic to all water studies. The quantity of water flowing into, through, and out of the river system was evaluated by a special SOR Work Group (ROSE: Reservoir Operation Simulation Experts). The Bonneville Power Administration's HYDROSIM model simulated the reservoir operations specified in the SOR strategic operating strategies. Fifty years of continual streamflow measurements taken within the system, starting in 1929, were input to the HYDROSIM model. The model simulated every alternative operation for this 50–year period, and output mean monthly (semi–monthly during March and April) discharges and pool elevations at each dam in the system.

### J–8.1.1 HEC–5Q – HYDROSIM Consistency

HEC–5Q uses methods similar to HYDROSIM to simulate discharge routing through the Columbia River system. Both models use one–dimensional hydrologic methods. Both models also use the same rating tables to define discharge as a function of forebay pool elevation, and forebay pool elevation as a function of storage volume and surface area of the reservoir. Hydrologic consistency is closely maintained between the two models. Discharge and pool elevations from the HYDROSIM model are input to HEC–5Q, then HEC–5Q computes the system's reservoir volumes and surface areas, and stream segment depths and velocities. The only difference rests with the calculation time steps – daily time step for HEC–5Q and monthly (or semi–monthly) for HYDROSIM.

### J–8.1.2 Worst Case Conditions

For the purposes of the SOR, the alternative SOSs had to be evaluated under extreme and average environmental conditions to determine the worst case and average scenarios for each alternative. River discharge was determined to be the most influential environmental factor on water quality in the Columbia River system. Three years were selected from the past 50 years to represent the low–, medium– and high–flow conditions. 1973 was selected to be the low–flow year, 1959 the medium–flow year, and 1974 the high–flow years. The worst case condition for water quality could not be presumed to occur necessarily during a high– or low–flow condition only. It could occur anytime within the range of extreme flows.

Worst case conditions also had to be specified to enable estimation of long–term accumulated effects. A five–year simulation duration was specified for the full–scale water quality model to mildly approximate these conditions. Extreme high–flow conditions were modeled for five years, with the first and last years using high–flow data from 1974, and the middle three years using medium–flow data from 1959. Extreme low–flow conditions were modeled for five years, with the first and last years using low–flow data from 1973, and the middle three years using medium–flow data from 1959. Average flow conditions weree modeled for five years using medium–flow data from 1959 for each of the five years.

### J–8.1.3 Computational Time–Step

A daily time–step was used for the simulations because of the large changes expected in daily discharges during the drawdown and refill periods proposed for the SOR drawdown alternatives. Mean daily discharges and pool elevations are used for each time–step. Only during drawdown and refill periods do the mean daily discharges and elevations change daily. Outside these periods, and for non–drawdown SOR alternatives, mean monthly discharges and elevations are fixed during each daily time–step throughout a particular month. March and April are special–case months, because they are modeled as two 15–day time periods. In this case, mean 15–day discharges and pool elevations are assigned to each day in that period.

### J–8.2 Meteorology

HEC–5Q requires meteorological data because air temperature, wind speed, and atmospheric radiation all drive the heat transfer mechanisms, which affect water temperature and chemical reaction rates. The model, however, is not very highly sensitive to meterological conditions. The COLTEMP model used meterological data from 1984. The full–scale water quality model continued using the same 1984 data for consistency.

### J–8.3 Sedimentation and Turbidity

Soil erosion and sediment scour have a major influence on water quality turbidity in particular especially during the proposed SOR drawdown alternatives. Turbidity is not modeled, but is calculated from the sediment concentrations in the water column. These concentrations are output from the full–scale water quality model simulations. Water quality standards exist for turbidity in the Columbia River system, and the model simulations provide data that could be used to determine the frequency of any exceedences in the turbidity standard.

### J–8.3.1 Bank Erosion and Bed Scour

Exposed reservoir banks and currently inundated sediment depositional zones on the channel bed at the head of the Snake River pools are likely sources of suspended sediment loading to the river. Bank soil erosion and bed sediment scour processes are included in the model, but are treated independently of one another. Sediment scour processes are represented in the HEC−6 model. The HEC−6 model output was combined with the results of a separate bank erosion analysis, then input into the HEC−5Q model, to account for the total sediment load to the system. Figure J−2 shows a schematic diagram of the two components of the sedimentation conceptual model.

The two models were integrated to achieve the sediment quality simulation capabilities required for the SOR. HEC−5Q is not as sophisticated in its computation of sediment transport quantities as HEC−6, but HEC−6 does not handle water quality. The enhanced HEC−5Q reads sediment inflow rates, assigns a bulk pollutant concentration to them, determines adsorption/desorption in the water column, then settles out the sediment as it is transported downstream. Sediment settling was already part of HEC−5Q. However, free−flowing stream segment settling (as opposed to a pool condition) was added during the enhancement. Scour computation capabilities were not added to HEC−5Q during enhancement, because they were already well established in HEC−6.

Four reservoir bank erosion processes are involved during a reservoir drawdown: (1) incision into tributary deltas; (2) slumping of reservoir sediments; (3) wave erosion; and (4) surface erosion during precipitation events. Incision, slumping, and wave erosion were measured from aerial photographs and land surveys taken during the March 1992 Lower Granite Dam drawdown test. Storm precipitation, and the duration and level of drawdown control the amount of incision. Slumping and wave erosion are controlled by the existence of terrace landforms in the reservoir banks and the level of drawdown, and not so much by the duration. In addition, wave erosion is also controlled by wind velocity. The surface erosion conceptual model is based on the theory underlying the Universal Soil Loss Equation. A more detailed discussion of the shoreline erosion model appears in Attachment J1.

The erosion generated by each of these four processes was calculated individually, summed, then combined with HEC−6 bed scour to determine the total sediment input into the HEC−5Q model of the drawdown pools. The erosion processes were assumed only to exist during reservoir drawdown. No bank erosion was assigned to non−drawdown reservoirs and SOR alternatives. Therefore, these processes were only simulated for Ice Harbor, Lower Monumental, Little Goose, and Lower Granite reservoirs, and for SOS 5 (natural river drawdown) and SOS 6 (partial drawdown).

Bed scour and bank erosion were estimated only for Lower Granite Pool. The only erosion and sediment data available were taken during the March 1992 drawdown test. The amount of erosion and scour inputs to the three other drawdown dams on the Snake River were based on extrapolations from Lower Granite.

### J–8.3.2 Sediment Deposition

Settling of sediments out of the water column was modeled in HEC−5Q. HEC−5Q modeled this process because of its capability to model water quality associated with sediments. HEC−6 is more sophisticated in its method of modeling deposition, but no water quality modeling is built into HEC−6. HEC−5Q relies on defining a bed shear threshold to control settling, and computes the deposition rate based on the suspended sediment concentration in the water column. When the computed bed shear exceeds this threshold, no deposition occurs.

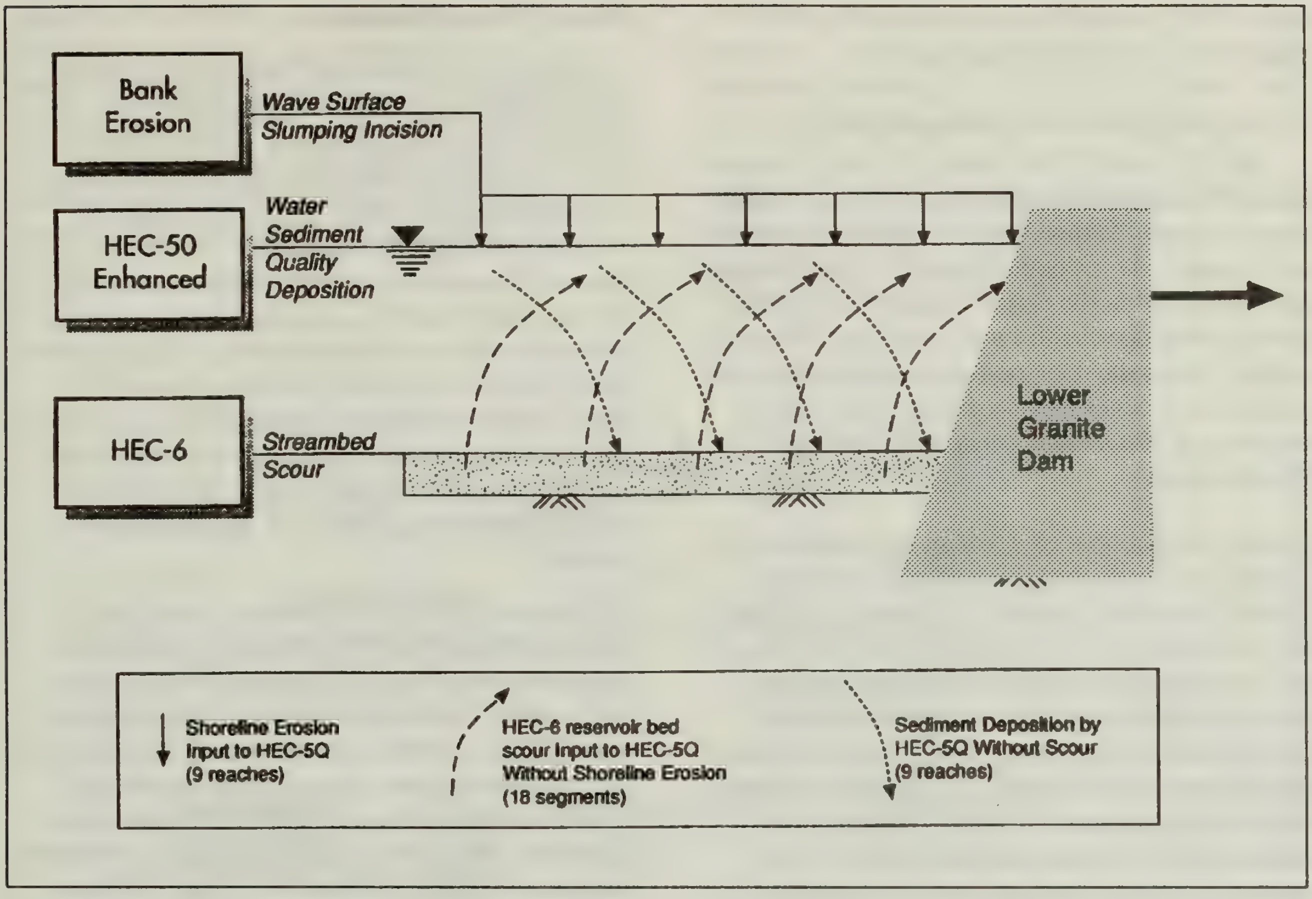

Bank Erosion
Wave Surface Slumping Incision
HEC-50 Enhanced
Water Sediment Quality Deposition
HEC-6
Streambed Scour
Lower Granite Dam
Shoreline Erosion Input to HEC-5Q (9 reaches)
HEC-6 reservoir bed scour Input to HEC-5Q Without Shoreline Erosion (18 segments)
Sediment Deposition by HEC-5Q Without Scour (9 reaches)

**Figure J–2. Sediment and Water Quality Model Integration**

### J–8.3.3 Computational Duration

The simulation time frame of the full–scale water quality models was primarily dictated by sedimentation processes. Erosion and scour are continuous processes that are in a dynamic equilibrium if left unaltered by human activities. Dams and drawdowns alter these processes, and a new state of dynamic equilibrium could be attained many years after dam construction, or pool drawdown. Also, the NEPA requirements for the SOR EIS include a discussion of accumulated effects over time due to the changes in system operation. The simulation time frame was selected to be long enough to let the sediment processes in the Columbia River system reach a new dynamic equilibrium, and allow a determination of long–term sediment accumulation. It was assumed that five years of repeated annual cycles of drawdown and refill would be required for these purposes.

### J–8.4 Bio–Chemical Parameters

Typical conventional water quality issues involve water temperature, dissolved oxygen, nutrients, and algae. HEC–5Q can model lake environments to address optimal reservoir operations to meet stated water quality and quantity targets. The phytoplankton option of HEC–5Q was activated for this study. Water temperature, total dissolved solids, nitrate nitrogen, phosphate phosphorus, phytoplankton, carbonaceous BOD, ammonia nitrogen, and dissolved oxygen were all simulated to provide a more realistic model of the bio–chemical processes within the Columbia River system that affect dissolved oxygen. In addition to modeling these conventional water quality parameters, HEC–5Q was enhanced for this study to model toxic parameters to the extent allowed by existing information.

### J–8.4.1 Nutrients and Phytoplankton

Inorganic nitrogen (including ammonia and nitrate), phosphorus, and carbon nutrient pathways between sources and sinks including phytoplankton exchanges are represented in the model. Sources are external loads to the reservoirs in the system from the atmosphere, tributaries, non–point sources, and the benthic zone. Sinks include downstream outflow, deposition to the benthic zone, and uptake by phytoplankton.

Uptake and digestion of nutrients by phytoplankton, and their return to the inorganic state via phytoplankton excretion, mortality, and decay is an internal cycle within the full nutrient cycle in the ecosystem. Phytoplankton growth is limited by temperature, the availability of these nutrients, and light penetration into the water column. Carbon dioxide and nutrients are consumed, and oxygen is released during photosynthesis. Oxygen is consumed and carbon dioxide and nutrients are released during respiration. Phytoplankton mortality is assumed to be attributed to zooplankton grazing, chemical treatment, and other factors (Corps, 1986). Dead phytoplankton decay and settle to the benthic zone, where they release phosphorous and ammonia back into the water column. Bacteria also consume oxygen in the process of breaking down phytoplankton.

HEC–5Q models these phytoplankton processes in combination with Columbia River system hydrology. Phytoplankton activity effects carbonate equilibriums, pH levels, and other water quality parameters, including toxins. Alteration of river discharges, reservoir levels and detention times are often used to control temperature, and promote downstream fish migrations in the Columbia River system. Phytoplankton growth is inhibited by high–water velocities. In slow moving reservoirs, phytoplankton growth can increase, resulting in decreased carbon dioxide ($CO_2$), increased dissolved oxygen (DO) and pH.

### J–8.4.2 Toxic Pollutants

The organic parameters DDT (modeled as the sum of DDT, DDE, and DDD) and PCB, the heavy metals mercury, lead and copper, and the dioxin 2, 3, 7, 8 TCDD were included in the full–scale water quality model. All of these toxins are heavily influenced by suspended particulates in the water column and on the bed. Particulates include clay, silt, and sand sediments, and phytoplankton. Toxic parameters tend to be hydrophobic, i.e., they adsorb to particulates more readily than they dissolve in water. Chemical adsorption mechanisms are responsible for sediments playing a large role in the transport of toxic pollutants. Figure J–3 shows a schematic diagram of how HEC–5Q models these processes.

Chemical sorption and diffusion are two of the major mechanisms shown in Figure J–3. Partitioning coefficients are used by HEC–5Q to quantify the strength of attraction between toxins and particulates. Toxin partitioning is defined for both the bed and the water column. In the bed, toxin mass can desorb into sediment pore water in the upper layer of the bed. The depth of the active layer is assumed constant in the HEC–5Q model. When particulates settle out of the water column, they add to the total depth of sediments in the bed, but only the active layer is allowed to release toxins into the water column. The mechanism controlling this release is diffusion. Pollutant mass is transferred across the bed surface into the water column at a rate determined by a toxin's diffusion coefficient and the concentration difference between the two media. Adsorption is by far a more significant process than diffusion in the Columbia River system especially during SOR drawdown alternatives.

### J–8.4.3 Toxic Sediments and Reservoir Drawdown

During drawdown, reservoir bank and bed sediments, and the toxic pollutants adsorbed to them, are vulnerable to scour and can be forced into suspension. This is where large masses of toxins adsorbed to bed sediments could be desorbed and enter the water column. The Snake River reservoirs have been trapping sediments and toxins since the dams were built. Dredging studies detected toxins in the lower Snake River reservoir sediments (Corps, 1992a). Enhancement of HEC–5Q allowed modeling toxic parameters in the reservoir banks and beds. HEC–6 and the bank erosion study estimated the sediment mass flux into the river. HEC–5Q assigned a constant concentration for each toxic parameter to the sediments entering each of the reservoirs. HEC–5Q then modeled the subsequent downstream transport and settling of sediments, and adsorption/desorption of toxins. Desorbed toxins that would enter the water column were advected downstream. Toxins remaining adsorbed to sediments would likely deposit on downstream beds.

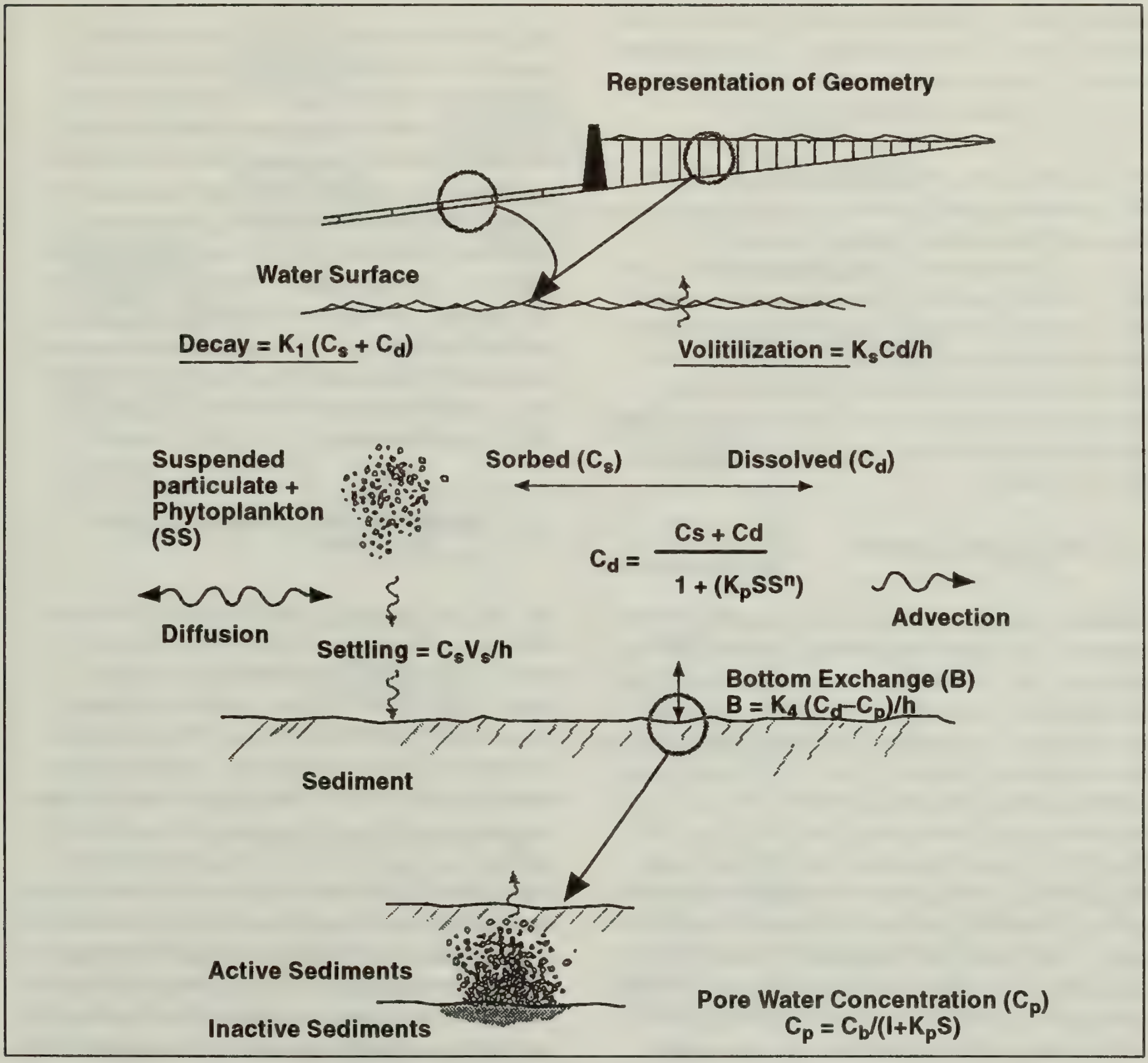


Figure J–3. Process Controlling Pollutant Kinetics as Represented by HEC–5Q (RMA, 1992)

## J–9 MODEL COMPONENTS AND DATA FLOW

The full–scale water quality model is composed of input data files, computer programs, and output files and graphs. The data flow between the model components is shown in Figure J–4. The programs in this figure are indicated by double outlined boxes, and the input and output files are indicated by single outlined boxes. The entire modeling system contains six programs and eleven data files. The content and purpose of each program and file is presented here in top down (input to output) order.

All programs, other than HEC–6, included in the full–scale water quality model were provided by Resource Management Associates (RMA). HEC–5Q is maintained by the Corps (at HEC), but the COLTEMP model and the enhanced version of HEC–5Q were developed by RMA specifically for the Columbia River SOR project, under the direction of the Corps and Ebasco. The SOR Water Quality Work Group provided technical commentary during the development stages of the enhanced HEC–5Q model.

## J–10 HEC–6 SIMULATIONS

Sediment processes were modeled using the HEC–6 program. The Corps' Walla Walla District, Hydrology Branch built the HEC–6 model and executed the simulations. A description of the HEC–6 inputs and results are included in Exhibit G (Corps, 1993) of this appendix. Generally, the 1992 Lower Granite Drawdown Test provided much of the data for construction and calibration of the HEC–6 model. The HEC–6 model simulated the SOR base case alternative (2a), both natural river drawdown alternatives (5a and 5b), and the two Lower Granite only, partial drawdown alternatives (6c and 6d). Each alternative was simulated for the extreme and average flow conditions that were assumed to bracket the range of the hypothetical worst case condition.

The unshielded HEC–6 model results were used in the full–scale water quality model. "Shielding" was encountered during initial simulations. It caused the fine–grained sediments nearest to Lower Granite Dam to remain unscoured during natural river drawdown simulations. The early simulations showed that sand scoured from the head of Lower Granite Reservoir was deposited on the downstream silt beds. This sand shielded the silt against scour.

The Corps recognized that the downstream silt deposits within Lower Granite Reservoir should scour due to "headcutting." The HEC–6 model does not represent this process in detail, and the simulations resulted in an underestimation of downstream silt bed scouring. The Corps compensated for this situation by reducing the percentage of coarse sand in the model. This compensation was referred to as "unshielding." Two approaches were taken during the HEC–6 modeling effort: unshielded and shielded. Unshielded simulations were only made of the natural river drawdown alternatives. All the other alternatives used the shielded HEC–6 model results.

## J–11 SEDIMENT INPUT PREPROCESSING

The INT program integrated the bank erosion and bed scour sediment fluxes that were computed for input to the lower Snake River portion of the Columbia River system with the reservoir sediment characteristics (SEDCHAR) file. The SEDCHAR file contained data describing the volume of sediments in the four lower Snake River reservoirs, the proportioning of contaminant mass among the bed sediment components, and average bed sediment contaminant concentrations. Sediment mass flux for each HEC–6 model reach was extracted for each time–step by the HEC6O5I program. The bank erosion analysis provided two data files: (1) a HEC–6 type rating table of flux versus discharge for each sediment grain component (see Appendix A); and (2) a discharge file containing daily values for three zones in Lower Granite Reservoir. These four files were processed by INT to provide input to HEC–5Q.

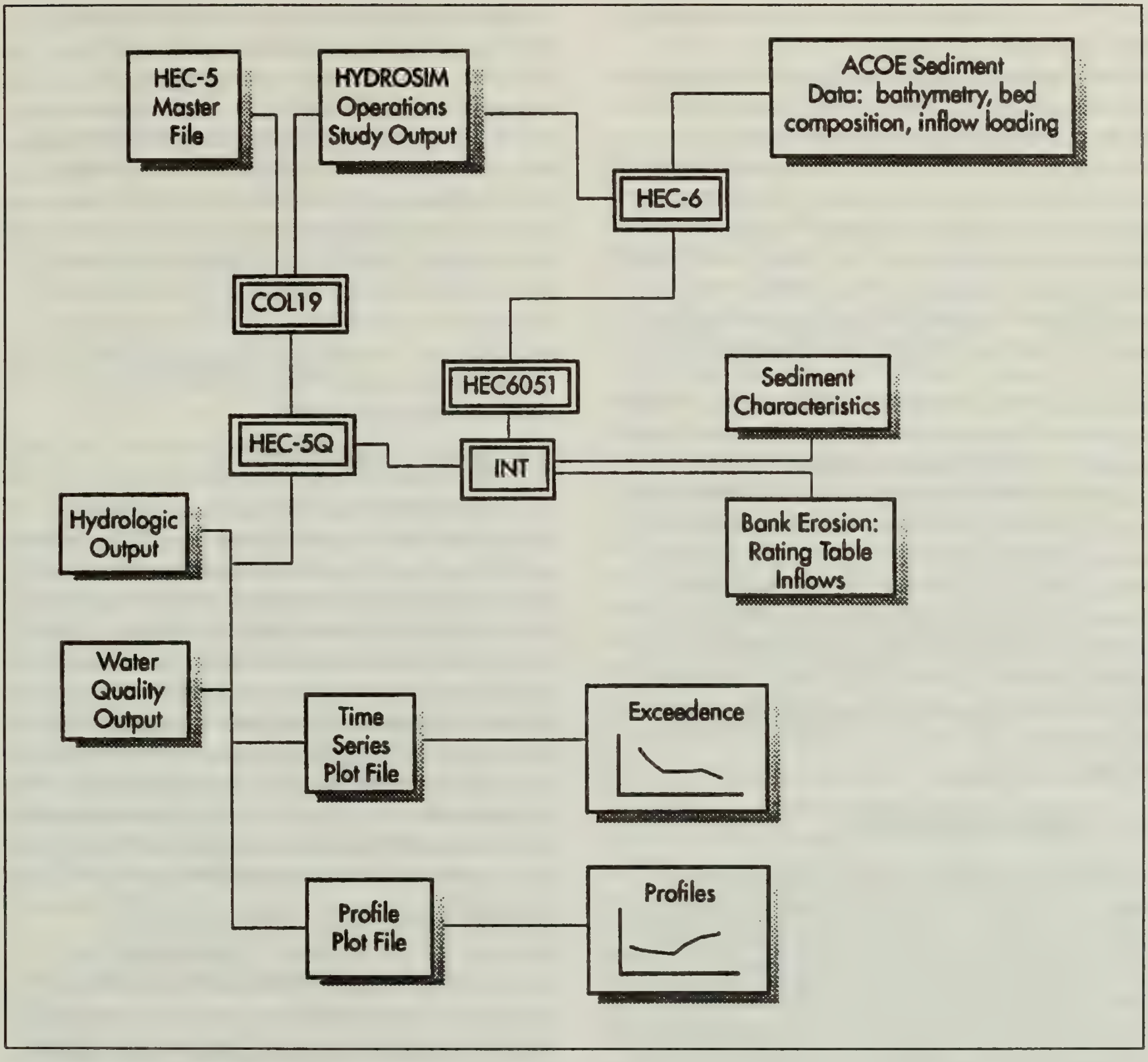


Figure J–4. Full–Scale Model Data Flow

The SEDCHAR file contains a record for each of the four reservoirs. The sediment volume parameter specified the ratio of estimated total accumulated sediment in a reservoir to the volume estimated for Lower Granite. The three proportioning factors were used to specify the percentage of total contaminant mass associated with clay, silt and sand sediments. Average sediment concentrations were specified for ammonia, nitrates, phosphates, DDT, PCB, Mercury, Lead, Copper, and TCDD. The combined bank erosion and bed scour sediment fluxes were assigned these concentrations. The total contaminant mass was separated into sediment component parts, then added to the suspended sediment load.

The sediment fluxes were computed for Lower Granite Reservoir only, so fluxes for Little Goose, Lower Monumental and Ice Harbor reservoirs were computed by extrapolating from Lower Granite data. The extrapolations were based on estimates of the total volume of sediment accumulation in the downstream reservoirs. The estimates accounted for the history of dam construction on the lower Snake River. Ice Harbor Dam, near the mouth, was constructed first, then Lower Monumental, Little Goose, and Lower Granite Dams. Sediment accumulated in Ice Harbor until Lower Monumental was built, and likewise on upstream. Now, Lower Granite is trapping sediments. The estimates were presented as percentages of the total sediment volume currently accumulated in Lower Granite Reservoir.

The rates of sediment scour were assumed to be the same for all the reservoirs, but the duration of scour was not. The INT program summed the HEC−6 simulated daily mass of sediments scoured from the bed of Lower Granite Reservoir. The same daily scour mass computed for Lower Granite Reservoir was applied to the downstream reservoirs on the Snake River. On the simulation day when the sediment scour sum exceeded a specified downstream reservoir's percent of the total Lower Granite Reservoir sediment volume, the INT program set the following daily scour rates within that reservoir to zero.

## J–12 COL19 MASTER FILE

The COL19 program combined the modified HEC−5Q master file with SOR specific hydrologic data. The full−scale water quality model is based on the previous COLTEMP model. When HEC−5Q enhancements were made, the COLTEMP input file was updated. The main update was the inclusion of the BPA's HYDROSIM operation system output files. Other changes were made to refine the tributary inflow and stream bed sediment concentrations, and to add the chemical properties of the additional toxic parameters. The refinement of inflow quality data entailed the inclusion of water quality data that were collected for the SOR to describe the current (1974 to present) conditions in the Columbia River Basin.

Initial conditions in the mainstem originally used in the COLTEMP model were also refined to meet the enhanced model's input data requirements. The COLTEMP model was built to simulate primarily water temperatures during the summer months of 1984 only. The full−scale water quality model extended COLTEMP to simulate water temperature as before, but for five years of each SOR alternative, while providing better detail for the conventional, phytoplanktonic and toxic parameters. RMA provided the meteorologic input data for the rest of 1984, and the Corps provided the hydrologic data. Ebasco refined the tributary inflow and stream bed parameter concentrations. The COL19 program inserted a year of operation study output into the master file, and copied it to an output file in HEC−5Q specified format.

## J–13 INITIAL CONDITIONS

The same initial conditions were used for each alternative−flow−condition simulation. The mainstem water column and bed sediment concentrations specified in the master file were estimated using a few data points. In order to avoid any inaccuracies in the initial condition estimates, the initial conditions file was created by simulating the base case alternative, under medium−flow conditions (1959), for one year. The state of the system was saved after this run for use as the initial conditions file. It was assumed that any over− or under−estimates of the initial conditions specified in the master file were attenuated within one simulated year.

The HEC−5Q model is traditionally set up to simulate one year at a time. This limitation required that the output of one year's simulation be used as the initial conditions input of the next year's simulation, over the course of the five−year simulation period.

## J–14 ENHANCED HEC–5Q

HEC−5Q was customized for application to the Columbia River SOR. The enhancements regarding toxic water quality parameter modeling were incorporated in the COLTEMP model. Further enhancements were made for full−scale water quality modeling of sediment inflows and transport. The output from the COL19 program provided the standard HEC−5Q input file combined with the specified year of hydrologic data from HYDROSIM. The output files generated by the INT program provided five simulation years of daily clay, silt, and sand sediment fluxes and water quality parameter bulk concentrations. HEC−5Q added sediment inputs to existing water column suspended sediments, then evaluated the water/particulate partitioning and the particulate settling rate as usual. Output from HEC−5Q can be quite voluminous, so a limited set of locations were specified for output of daily results.

### J–15 HEC–5Q OUTPUT FILES

Four files are output from HEC−5Q: (1) the end−of−year conditions file; (2) the main output file; (3) the profile file; and (4) the time series file. The profile file is for plotting longitudinal profiles of parameter concentrations in the water column within each main branch of the Columbia River system. The time series file contains concentration daily output from John Day, Priest Rapids, Ice Harbor and Lower Granite Dams. Also, sediment accumulation time series data is output to a time series file at two reaches in Lake Umatilla, and three reaches in Lake Wallula. The water column time series data were used to calculate the frequency of water quality standard exceedences. The sediment accumulation time series data were used to show when and if sediment transport reaches equilibrium.

### J–16 LONGITUDINAL PROFILE PLOTTING

A graphic post−processing program was used to plot an instantaneous longitudinal profile of simulated water quality parameter concentrations within the water column and bed sediment. The profiles were plotted from Bonneville Dam, upstream to Grand Coulee, Brownlee, or Dworshak Dams. The profile data were output once each month. Profiles for a maximum of three days could be plotting on one graph. Accumulated silt sediments were plotted along the Columbia River for December of each of the five years in a simulation to show the deposition of sediment load below the confluence of the Snake River.

### J–17 WATER QUALITY DATABASE

The EPA, USGS, and Corps' water quality databases provided Columbia River system water column total and dissolved, and sediment bulk concentrations, for the conventional and toxic (DDT, PCB, mercury, lead, copper, and TCDD) parameters. Ebasco performed an initial scan of the databases that resulted in the selection of these toxins for inclusion in the full−scale water quality model. Each of the major tributaries to the Columbia and Snake Rivers in the SOR study area was assigned a water column total concentration for each modeled parameter. The water column total concentrations for all the parameters simulated in the full scale water quality model are shown in Table J−1. All reservoir and stream reaches in the mainstems were assigned a bed sediment bulk concentration for only the toxic parameters in the model. Concentrations were estimated where insufficient data existed for a particular tributary or mainstem reach. A large majority of the concentrations were estimated because of the lack of existing water quality data.

### J–18 INITIAL SCREENING OF TOXINS

The selection of the toxic water quality parameters for inclusion in the model was primarily based on EPAs STORET database. The EPAs' INVENT program was used to retrieve a summary of all water quality parameters monitored after 1973 in the Columbia River from its mouth to the International boundary, and in the Snake River from its mouth to the Washington−Idaho border near the Clarkston−Lewiston area. The summary included for each water quality parameter the number of observations, and the mean, maximum, and minimum concentration statistics. These concentrations were evaluated based on their frequency of observation, the exceedence of water quality standard, the partitioning coefficient, and toxicity to fish and humans. An initial set of 40 parameters was selected based on the number of observations and previous knowledge of their probable cause of concern to the system. The 40 parameters were grouped into three tiers of risk. The toxins included in the full−scale water quality model were selected from the high risk tier. See Attachment J2 for a detailed discussion of this screening process.

## J–19 TRIBUTARY / HEADWATER WATER COLUMN DATA

The USGS database provided most of the water quality data for toxins included in the full–scale model. Data were retrieved for the Upper Columbia tributaries (Wenatchee, Chelan, Methow, and Okanagan Rivers), the Yakima, Salmon, Grande Ronde, Clearwater, Palouse, John Day, Deschutes, and Klickitat Rivers. Mainstem inflow quality for Lake Roosevelt, Dworshak Reservoir, and Brownlee Reservoir were also retrieved. The North Fork of the Clearwater River flows into Dworshak Reservoir, but there were no useful water quality data available for this river. The USGS station on the South Fork of the Clearwater River was used to represent the inflow quality to Dworshak Reservoir. The USGS station at Weiser, Idaho on the Snake River was used to represent the quality of the Snake River Inflows to Brownlee Reservoir, and the USGS station at Northport, Washington was used for Lake Roosevelt. The data collected at the USGS station on the Moxee Drain near Union Gap, Washington were used to represent non–point sources.

## J–20 MAINSTEM BED SEDIMENT DATA

Water column data were available for most of these locations, but sediment data were sparse. EPAs STORET database provided data on mercury and lead concentrations in Lake Roosevelt sediments. The USGS database provided some sediment concentration data for DDT in the Yakima River, Snake River at Weiser, Idaho, and for heavy metals in Lake Roosevelt at Northport, Washington. The Corps provided Snake River dredging reports (Corps, 1992b; Corps, 1991b; Battelle, 1989; Corps 1985) that contained sediment quality data from the Columbia River near the confluence with the Snake, the mouth of the Snake River, and in Lake Sacajawea near Sheffler, Lake Bryan near Almota, Lower Granite Lake between Blyton Landing and the confluence with the Clearwater River, and the mouth of the Clearwater River. The EPA also provided dioxin data on Snake River sediments in Lower Granite Lake (EPA, 1993). Also the EPA STORET INVENT retrieval program, that was used in initial parameter screening, provided the whole study area's mainstem average sediment concentration for all the parameters.

## J–21 WATER QUALITY DATA AVAILABILITY

Where no water quality data were available, data from the COLTEMP model were used to provide water column and sediment concentrations, and existing data from reference tributaries were extrapolated. The COLTEMP model contained estimates of typical water quality parameter concentrations for all the tributaries in the model. More precise estimates were required for the toxic parameters, because COLTEMP toxic data did not fully represent all the toxic parameter issues in the system. Four water quality reports were reviewed to ascertain toxic water quality problems in the Columbia River system:

- The Corps' water quality annual report (Corps, 1991c)
- EPA report to the Northwest Power Planning Council (Kelley et al., 1992)
- USGS expert opinion poll on water quality issues (USGS, 1992)
- The Washington Department of Ecology (WDOE) 305b report (WDOE, 1992)
- The Oregon Department of Environmental Quality (ODEQ) 305b report (ODEQ, 1992).

These reports are based on professional judgments, but they are not always substantiated by water quality monitoring reports. Table J–2 shows which tributaries were reported to have toxic water quality problems, and if data were found to quantify the problem. If a water quality problem was identified in one of these reports at a specific location or reach, and no data were available there, then existing data from the nearest reference tributary were extrapolated to estimate the missing data.

### J–21.1 Estimation of Algal Data

HEC–5Q models phytoplankton biomass using units of mg/l, but most data obtained from EPA STORET and USGS databases were reported in units of cells per ml. The database cell density values were multiplied by 0.0005 to convert them into biomass as mg/l. The system average obtained from EPA STORET is

## Table J–1. Tributary Inflow Concentrations Used in the HEC–5Q Model

| | HEC–5Q Modeled | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TDS | $NO_3$ | $PO_4$ | Algae | CBOD | $NH_3$ | DO | Cl | ALK | pH | DDT | PCB | Hg | Pb | Cu | Dioxin | Clay | Silt | Sand | Fecal Col. |
| Tributary | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | S.U. | ug/l | ug/l | ug/l | ug/l | ug/l | ug/l | mg/l | mg/l | mg/l | #/100ml |
| Dworshak Inflow | 46.7 | 0.050 | 0.034 | 0.30 | 5.0 | 0.011 | 13.2 | 0.87 | 22.6 | 7.8 | 0.0000 | 0.0000 | 0.081 | 2.194 | 4.140 | 0 | 5.95 | 5.95 | 4.40 | 65.0 |
| Brownlee Inflow | 248.6 | 0.502 | 0.054 | 11.0 | 9.4 | 0.058 | 9.8 | 15.80 | 144.7 | 8.2 | 0.0040 | 0.0000 | 0.232 | 63.3 | 29.8 | 0 | 21.46 | 21.46 | 15.88 | 358.0 |
| Salmon/G.R. Rivers | 131.5 | 0.045 | 0.064 | 0.50 | 8.0 | 0.054 | 12.9 | 3.19 | 72.7 | 8.2 | 0.00083 | 0.0000 | 0.291 | 63.2 | 2.1 | 0 | 25.92 | 25.92 | 19.17 | 148.0 |
| Clearwater R. Flow | 35.4 | 0.276 | 0.046 | 0.30 | 5.0 | 0.062 | 10.9 | 0.68 | 18.7 | 7.2 | 0.00232 | 0.0000 | 0.245 | 29.7 | 9.1 | 0 | 5.95 | 5.95 | 4.40 | 126.0 |
| Palouse R. Flow | 75.0 | 0.393 | 0.138 | 1.00 | 12.0 | 0.141 | 11.2 | 1.73 | 30.0 | 7.4 | 0.0000 | 0.0000 | 0.324 | 38.0 | 35.1 | 0 | 5.95 | 5.95 | 4.40 | 134.0 |
| Grand Coulee Inflow | 81.3 | 0.091 | 0.028 | 1.22 | 9.0 | 0.050 | 11.8 | 0.97 | 58.8 | 7.8 | 0.0019 | 0.00009 | 0.200 | 51.4 | 20.5 | 0 | 1.42 | 1.42 | 1.05 | 16.0 |
| Upper Columbia Trib. Flow | 84.4 | 0.112 | 0.035 | 1.78 | 12.0 | 0.036 | 11.3 | 1.49 | 63.4 | 7.8 | 0.0021 | 0.00009 | 0.177 | 33.7 | 6.070 | 0 | 12.52 | 12.52 | 9.26 | 62.0 |
| Yakima R. Flow | 94.0 | 0.918 | 0.131 | 5.00 | 18.2 | 0.039 | 10.4 | 3.00 | 103.6 | 8.1 | 0.00190 | 0.000 | 0.289 | 30.1 | 10.3 | 0 | 17.81 | 17.81 | 13.18 | 151.0 |
| John Day R. Flow | 150.0 | 0.060 | 0.042 | 1.00 | 15.0 | 0.017 | 11.2 | 3.30 | 118.0 | 8.4 | 0.0000 | 0.0000 | 0.258 | 21.060 | 10.910 | 0 | 8.10 | 8.10 | 5.99 | 36.7 |
| Deschutes R. Flow | 90.0 | 0.130 | 0.061 | 1.00 | 12.0 | 0.017 | 11.4 | 2.20 | 61.1 | 8.1 | 0.0000 | 0.000 | 0.165 | 26.230 | 13.250 | 0 | 6.64 | 6.64 | 4.91 | 4.0 |
| Klickitat R. Temp | 70.0 | 0.134 | 0.077 | 0.29 | 10.0 | 0.037 | 11.3 | 1.50 | 33.2 | 7.7 | 0.0000 | 0.0000 | 0.339 | 31.7 | 8.750 | 0 | 13.18 | 13.18 | 9.75 | 13.3 |
| Pulp Mill Mass Loadings | 500.0 | 1.000 | 0.300 | 0.00 | 100.0 | 5.400 | 4.0 | 50.00 | 100.0 | 9 | 0.0000 | 0.0002 | 0.480 | ***** | 0.000 | 0 | 60.00 | 60.00 | 60.00 | 1000.0 |
| Non Point to Lower Snake/Col | 175.0 | 1.200 | 0.270 | 1.00 | 15.0 | 0.030 | 9.1 | 7.30 | 137.0 | 8 | 0.03600 | 0.0000 | 0.324 | 40.4 | 19.600 | 0 | 255.51 | 255.51 | 0.00 | 151.0 |

2.72 mg/l (5438.3 cells/ml). The range of algal concentrations found in STORET was between 0.12 and 21.5 mg/l (240–43000 cells/ml). The 0.0005 conversion factor was selected because the range and average of converted EPA STORET biomass concentrations were close to published values. A range of 0.23 to 17.7 mg/l (460–35400 cells/ml), and an average of 1.36 mg/l (2720 cells/ml) were found to be typical values (Kendeigh, 1974).

### J–21.2 Estimation of Organic Parameter Data

The Yakima River was used as a reference tributary for DDT data extrapolation because it has been extensively monitored by the USGS for all the water quality parameters included in the full–scale model. Also the Washington 305b (WDOE, 1992) report evaluated the number of Yakima River miles that were impacted by a number of different causes and sources. The ODEQ and WDOE 305b reports also included the number of impacted river miles for all the rivers in Oregon and Washington, respectively. DDT, DDE, and DDD concentrations reported by the USGS for the Yakima River were normalized to the number of impacted river miles on the Yakima that were reported by WDOE. The normalized Yakima River concentrations were multiplied by the number of impacted river miles published in the 305b reports to estimate concentrations in other tributaries.

### Table J–2. Potential Water Quality Issues and Available Data

| | Identifying Agency$^{1/,\ 2/}$ | | | | | |
|---|---|---|---|---|---|---|
| Subbasin | Pesticides | Dioxins | PCBs | Metals | Bacteria | Algae |
| Dworshak Inflow | – – | – – | – – | – – | *,– – | – – |
| Brownlee Inflow | *,2 | – – | *,– – | *,– – | *,2 | *,2 |
| Salmon/Grande Ronde | 2 | — | – – | *,2 | 2,5,4 | – – |
| Clearwater | 2 | — | 2 | *,2 | *,2 | *,– – |
| Palouse | — | – – | – – | 2,4 | *,2,4,3 | – – |
| Grand Coulee Inflow | 2,3 | 2,3 | 2,4 | *,2,3 | *,2,3 | *,1 |
| Upper Columbia Tributaries | 2,3 | – – | – – | *,– – | *,2,3 | *,– – |
| Wenatchee | – – | – – | 4 | – – | – – | – – |
| Yakima | *,2,3,4 | – – | *,2 | *,2 | *,2,3 | *,2,3 |
| John Day | – – | – – | – – | *,– – | *,2,5,3 | – – |
| Deschutes | – – | – – | – – | *,– – | *,2,3 | – – |
| Klickitat | – – | – – | – – | *,– – | *,2,3 | *,– – |

1/ Agency codes:
1 – Corps
2 – EPA
3 – USGS
4 – WDOE
5 – ODEQ

2/ * – Data Available
– – – Not Identified as an Issue

Of all the toxic parameters modeled, the least amount of data was found for the organics: DDT, PCB and TCDD. Yakima River DDT, DDE and DDD sediment concentrations retrieved from the USGS database were extrapolated using this method to estimate concentrations in the other modeled tributaries that were reported to have pesticide problems. EPA identified pesticide problems in the mainstem Columbia River above Chief Joseph Dam, and Snake River above Hells Canyon. EPA also identified pesticide problems in the tributaries: the Salmon, Clearwater, Wenatchee and Okanogan Rivers. DDT concentration estimates were made for all these headwater and tributary inflows.

PCB issues were reported by the EPA and WDOE, but no reliable data on PCBs were found for any location in the Columbia River system. EPA identified PCB problems in the mainstem Columbia River above Bonneville Dam to Priest Rapids, and in Lake Roosevelt. WDOE identified PCB problems in the Wenatchee River. Also, EPA identified PCB problems in the Clearwater River, but no PCBs were found in the Snake River sediments (Corps, 1992a). PCB data retrieved from EPAs STORET database showed a sufficient PCB concentrations in the Columbia and Snake Rivers to justify its inclusion in the model. However estimates of PCB concentrations were based on only a few data points, so simulated PCB concentrations should be carefully weighed.

Dioxin (TCDD) data were not made available in amounts that support full scale modeling objectives. TCDD data were only available for the Snake River, but the EPA identified dioxin problems in the entire mainstem Columbia River within the study area. The order of magnitude of TCDD bulk concentration measured in the Snake River (and in the Columbia River near the confluence) sediment was in single parts–per–trillion. These levels are lower than is typically modeled by HEC–5Q. The lack of TCDD monitoring, and the HEC–5Q model low concentration limitation again call for careful consideration of TCDD simulation results.

### J–21.3 Estimation of Heavy Metal Parameter Data

Mercury, lead, and copper, unlike PCB and TCDD, were regularly monitored during the study period. Although, water column monitoring of these heavy metals was more extensive than sediment monitoring. Lead and mercury sediment concentrations for Lake Roosevelt were retrieved from STORET. The USGS database provided most of the water column data. Total water column concentrations were more available than dissolved. Some total concentrations were unknown, and had to be estimated from known dissolved concentrations. When neither total nor dissolved were concentrations were known the system average concentration was used. The system averages for heavy metals were retrieved from STORET.

## J–22 RESULTS

Total water column concentrations of algae (phytoplankton biomass), ammonia (total ammonia nitrogen), total DDT (DDT, DDE, and DDD combined), total lead, and silt only were summarized. These parameters were selected because they represent a parameter or process category. Lead is an indicator of most of the modeled heavy metals, DDT of organic pesticides, and silt of inorganic particulates. Algae is an indicator of the biologic processes, and ammonia of the nutrient cycles in the system. The discussion of results is limited to these five water quality parameters, and only the most significant results are highlighted in the text.

## J–23 RESULTS ANALYSIS AND SUMMARIZATION

The model results were summarized on spatial and temporal bases. Comparisons of spatial variations were made for: (1) longitudinal concentration profiles of the major system branches at specific instances of time; and (2) concentration exceedences at four specific locations. Longitudinal profile plots of concentrations along the Columbia and Snake River branches are shown in Figures J–32 to J–58; and Figures J–72 to J–78. Concentration exceedence duration analyses were performed to describe system effects over time. Plots showing the percent of time that various concentrations of these water quality parameters are exceeded as shown in Figures J–59 to J–69; and Figures J–79 to J–90. All those plots are designed to demonstrate the potential water quality effects of the SOSs. SOR system operations alternatives are compared by inspection of time and spatial trends of the five representative parameters.

### J–23.1 Concentration Exceedence Duration

Exceedence graphs were used to summarize the model results at four locations in the system: (1) John Day Dam; (2) Priest Rapids Dam; (3) Ice Harbor Dam; (4) Lower Granite Dam (see Figure J–1). A table was made for each alternative–condition–parameter combination. Exceedences were computed from the daily output files of HEC–5Q simulated concentrations. The range of simulated concentration values for each of the five parameters were divided into ten intervals. The number of days during the simulation period that the concentration exceeded each interval was computed. In addition to the exceedence tables, silt accumulation profiles are presented for the Columbia River for each simulation year and alternative–condition combination.

### J–23.2 Longitudinal Concentration Profiles

Longitudinal profiles of the five parameter concentrations primarily were plotted along the Bonneville Dam to Brownlee Dam branch of the system. This branch is emphasized because the main purpose of the modeling effort was to show the differences between the drawdown and non–drawdown alternatives, and the drawdowns are only proposed for the lower Snake River. The mid–Columbia branch of the system (above the confluence with the Snake River) was used only as an upstream baseline condition.

The Snake River portion of the Bonneville to Brownlee profile plots show potential sediment scour effects on water column concentrations, and the lower Columbia portion show the potential sediment accumulation effects. The number of lower Snake River pools to be drawn down, and the durations vary between the drawdown SOSs. The longitudinal profile plots of concentrations in Bonneville to Brownlee branch indicate the varying level impacts expected from the six modeled SOR drawdown alternatives.

### J–23.3 Worst and Average Cases

The model results were evaluated to determine the worst case water quality impacts from the drawdown alternatives during the first year of operation, and over the long–term. Drawdown operations are expected to transport the most sediment during the initial reservoir bed scouring. Sediment loading is expected to decrease after repeated annual reservoir drawdowns scour the previously buried stream channels to form a new equilibrium slope and shape. Only bank erosion and upstream inflows continue to supply sediment over the long–term. Exceedence and profile plots for the worst case condition in the first and second year are presented to show potential short–term impacts. The mean five year exceedences for low, medium, and high–flow conditions were computed to indicate the long–term effects.

## J–24 ALGAE

The main features of the algae simulations are:

- Algal biomasses discharging from Brownlee Reservoir rapidly decline through Hells Canyon at lower flows, but not at high flows.
- The Snake River contributes more algae to the lower Columbia than the mid–Columbia River.
- No significant differences between SOR alternatives.
- Biomasses are higher at low flows than at high flows, except at Lower Granite.
- Exceedence of above average biomass is greater during high flows than at low flows in the lower Snake River.

Simulation results demonstrating these main points are plotted in Figures J–5 through J–17.

High outflows of springtime (day 105) biomass from Brownlee Reservoir are reduced in the Hells Canyon reach by dilution from major tributaries, but remain relatively steady through the Lower Snake River. Figure J–5 and J–6 show base case algae profiles under average flow conditions for the Snake and Columbia River branches, respectively. Comparison with the profiles in Figures J–7 through J–9 shows that the high flows tend not to reduce the biomass as much through Hells Canyon (upstream of river mile 475). The concentration decreases slightly in the Snake river downstream of Lower Granite to its mouth. However, Snake River concentrations are greater than Mid–Columbia River concentrations at their confluence. Columbia River biomass is increased by Snake River flows as shown in Figure J–6 near river mile 340.

The difference between SOS exceedences of the systemwide average biomass (2.5 mg/l), as shown in Figures J–10, J–11, J–12 and J–13, are negligible. The only noticeable differences are between the 4½–month and 2–month full–river drawdown SOSs at Ice Harbor and John Day Dams during the first simulation year. The 4½–month drawdowns show a lower exceedence than the 2–month drawdowns at low flow. The model produced mostly the same results at Lower Granite, Priest Rapids, and John Day Dams for all SOSs.

Low–flow algal exceedences are highest at Ice Harbor and John Day Dams for year one current operation simulations, but upstream at Lower Granite, the model showed highest exceedences at high flows. Figure J–10, J–11, J–12 and J–13, show the exceedences of 2.5 mg/l algae for the first two years at high and low flows. High inflows carry the greatest biomasses into Lower Granite Reservoir which results in the highest exceedences at this upstream most dam on the lower Snake. Downstream however, the model results indicate that high flows flush algal biomass out of downstream reservoirs on the lower Snake and Columbia Rivers.

The main exceedence differences are between flow conditions. Figures J–14, J–15, J–16 and J–17 show the algal biomass exceedence curves for alternatives 2a and 6a. These alternatives are typical of all the alternatives. The 2a and 6a curves are grouped close together, but the "MED" (average) flow curves are lower on the Snake River. High–flow simulations of the Snake River produced the greatest exceedences of above average algal biomasses. On the Columbia River, John Day exceedence curves are highest at low flows, but at Priest Rapids all flows have about the same curve. The overall increase in exceedences from Priest Rapids to John Day shown by these curves provides further supporting evidence that the Snake River increases lower Columbia River algal biomass.

As stated earlier, alternative 2a was used as base case. Results predicted for this alternative were assumed to be the same as those of alternative 2c used as base case for water temperature and dissolved gas.

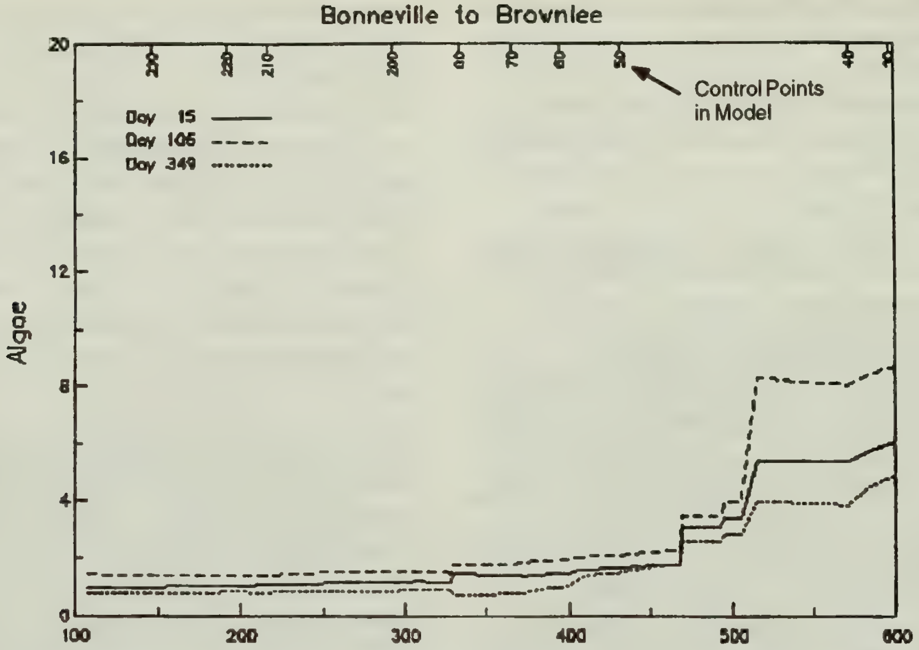


**Figure J–5.** **Algal concentrations (mg/l) from Bonneville to Brownlee Average Flow, Year 1, Alternative SOS 2a**

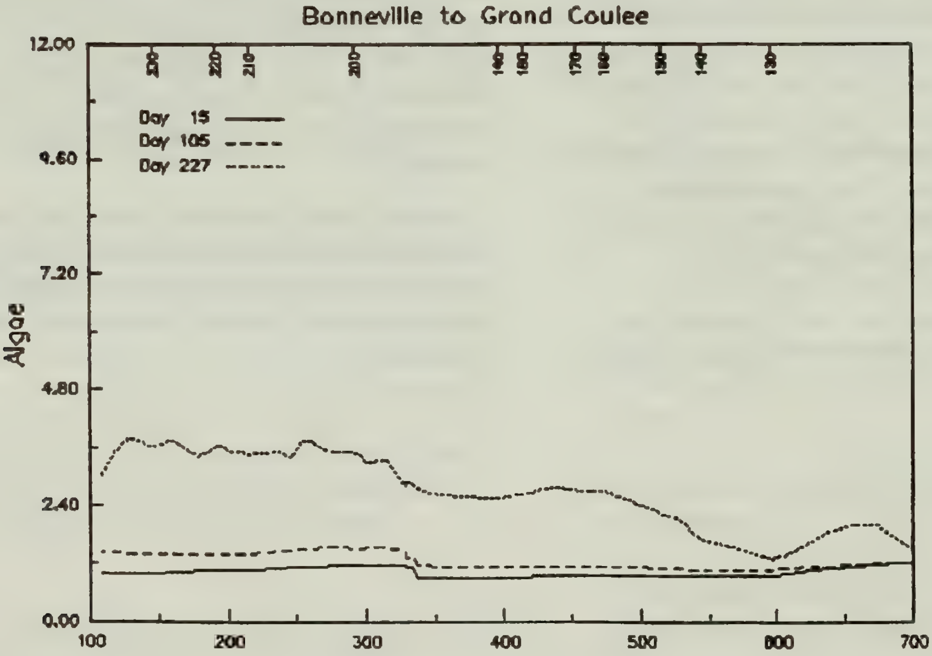


**Figure J–6.** **Algal concentrations (mg/l) from Bonneville to Grand Coulee, Average Flow, Year 1, Alternative SOS 2a**

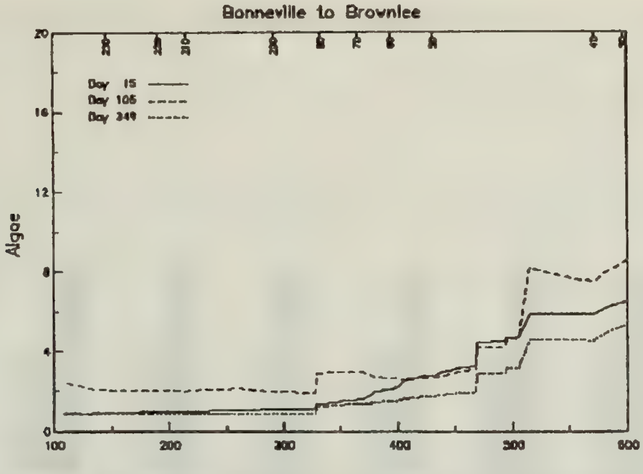


Figure J–7. Algal Concentrations (mg/l) from Bonneville to Brownlee, Low Flow, Year 1 Alternative SOS 6a

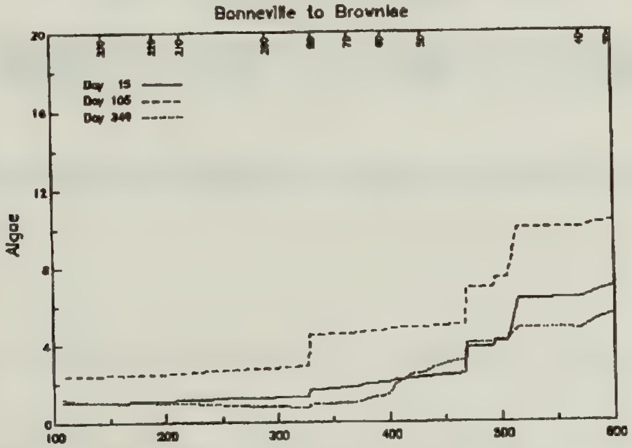


Figure J–8. Algal Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 1 Alternative SOS 6a

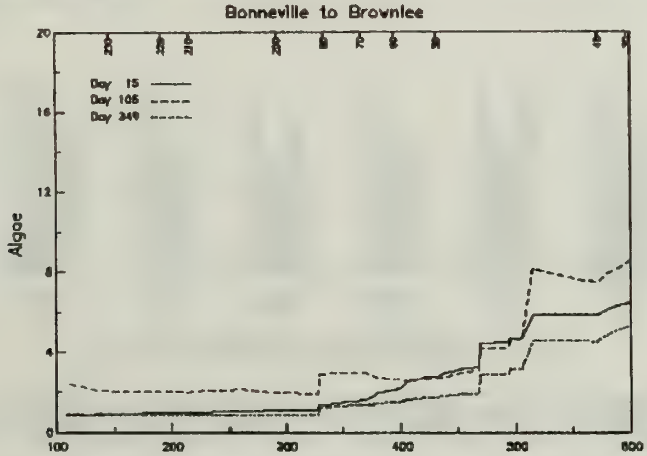


Figure J–9. Algal Concentrations (mg/l) from Bonneville to Brownlee, High Flow, Year 1 Alternative SOS 6a

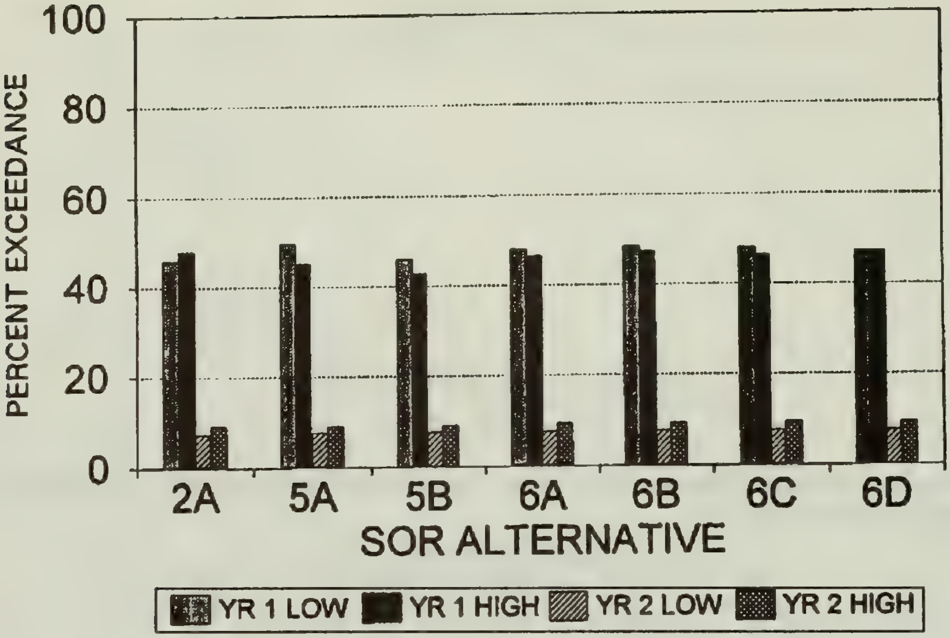


Figure J–10. Exceedence in Year 1 and 2 2.5 mg/l Algae at Lower Granite

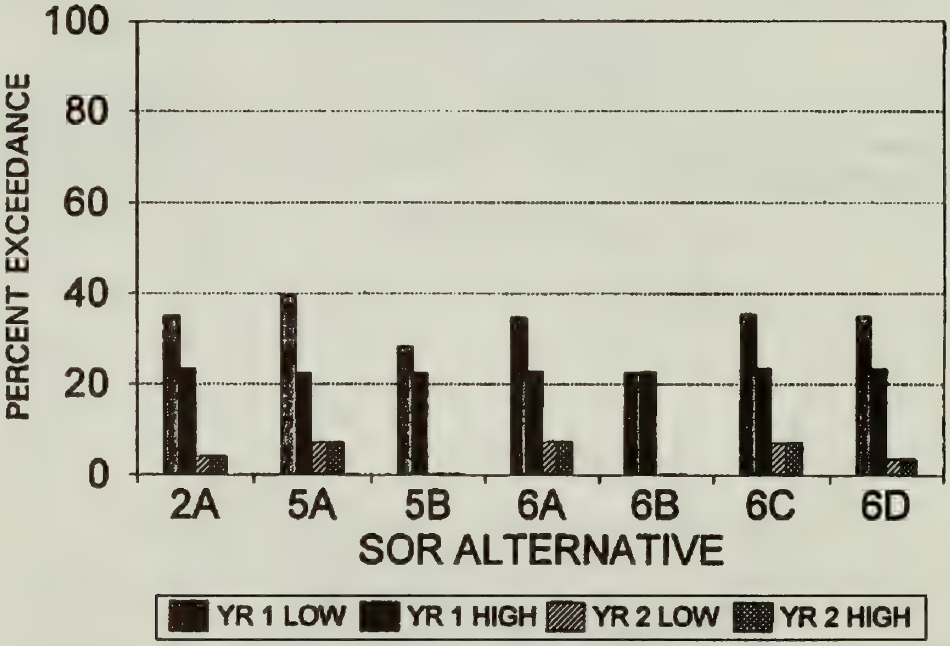


Figure J–11. Exceedence in Year 1 and 2 2.5 mg/l Algae at Ice Harbor

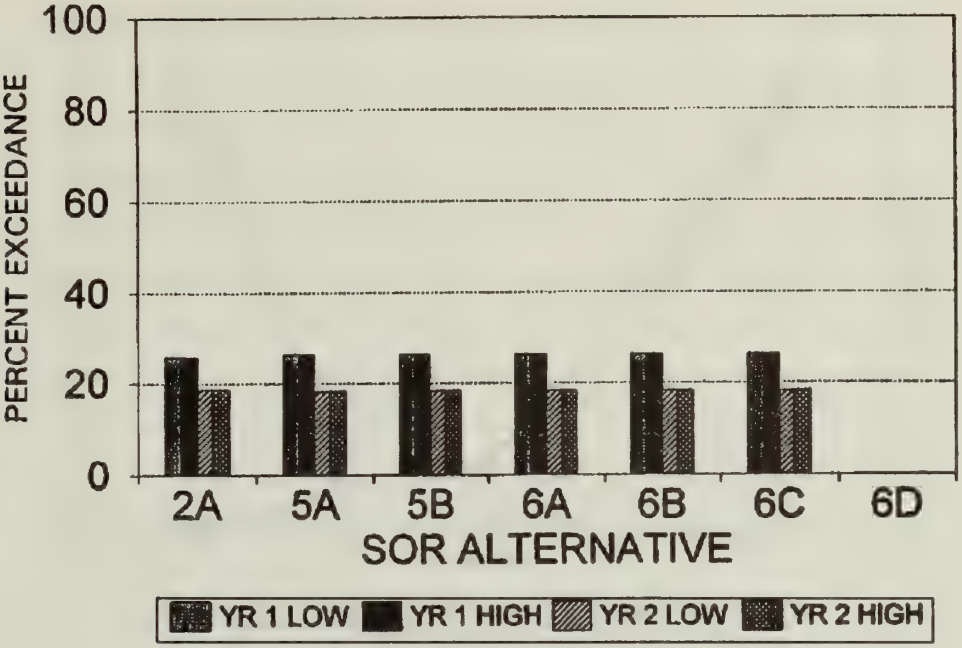


**Figure J–12.** **Exceedence in Year 1 and 2 2.5 mg/l Algae at Priest Rapids**

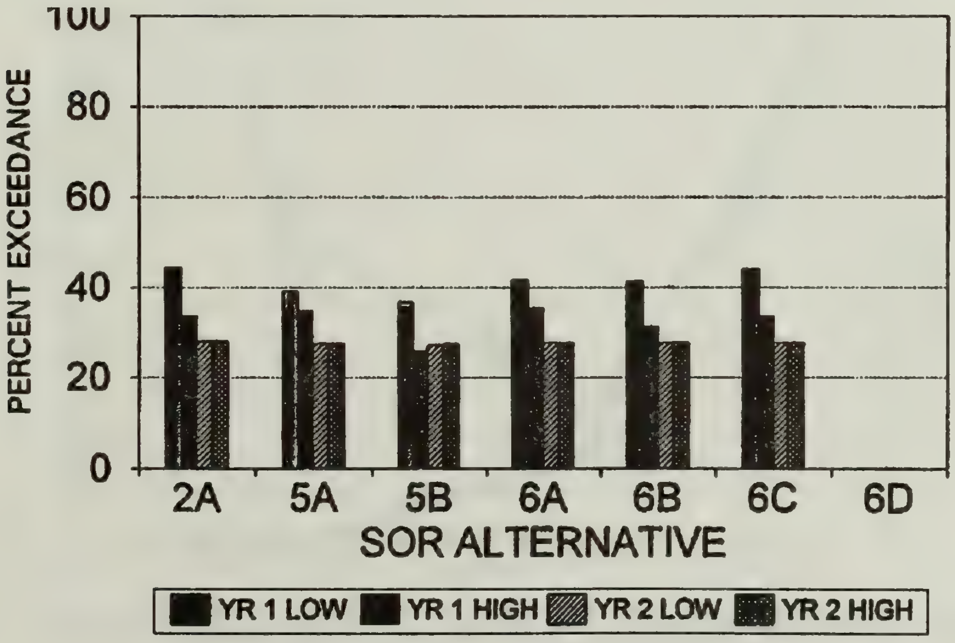


**Figure J–13.** **Exceedence in Year 1 and 2 2.5 mg/l Algae at John Day**

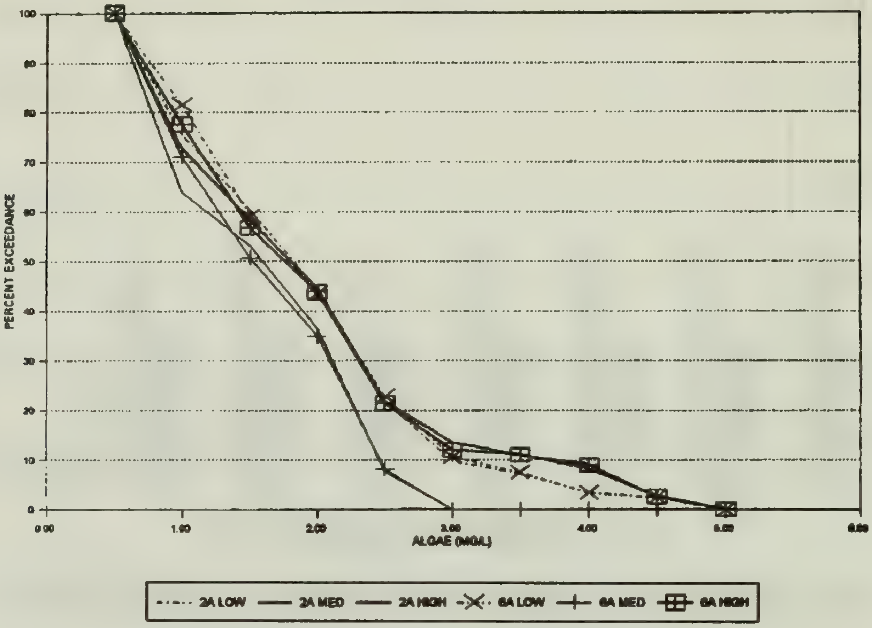


**Figure J–14.** 5–Year Exceedence for Algae at Lower Granite Dam for Alternative SOS 6a

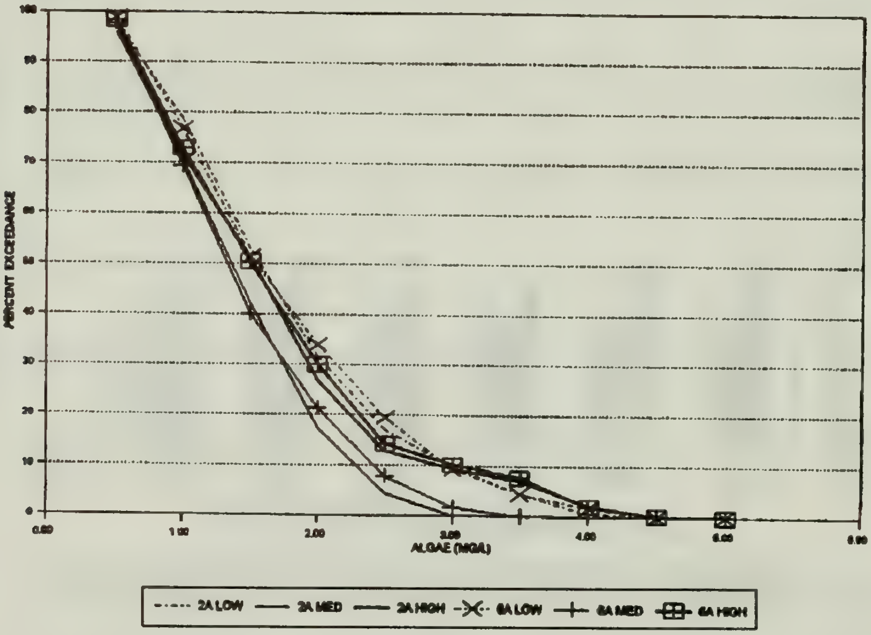


**Figure J–15.** 5–Year Exceedence for Algae at Ice Harbor Dam for Alternative SOS 6a

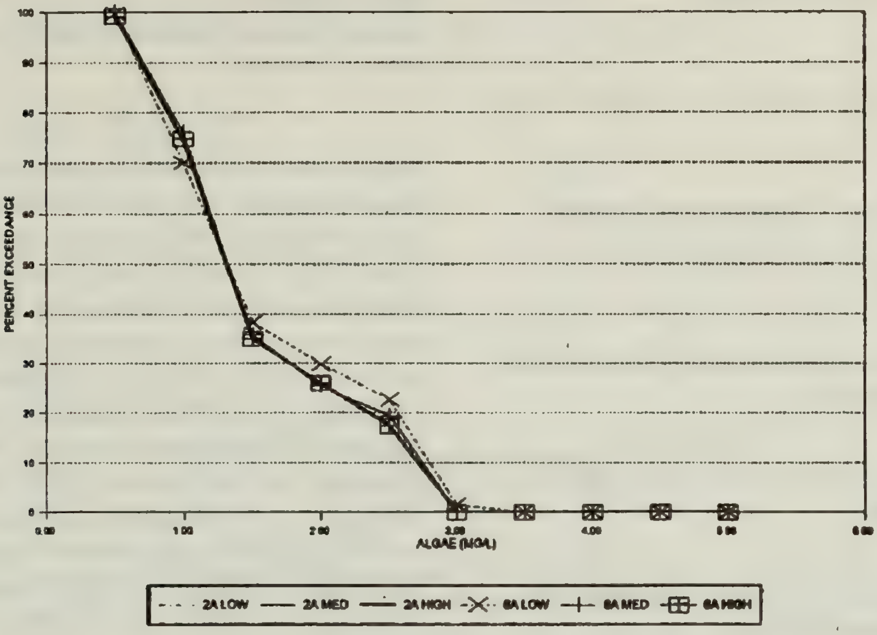


**Figure J–16.** **5–Year Exceedence for Algae at Priest Rapids Dam for Alternative SOS 6a**

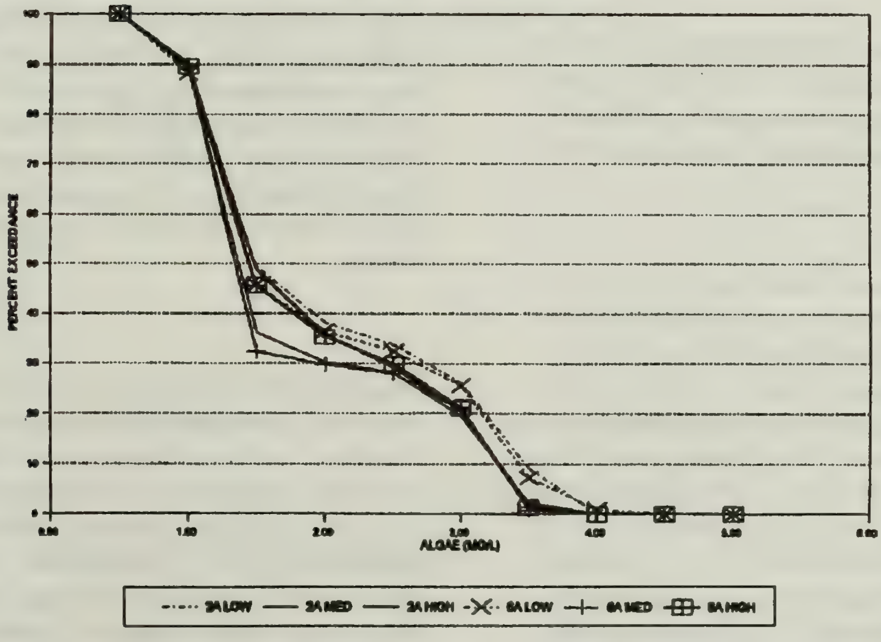


**Figure J–17.** **5–Year Exceedence for Algae at John Day Dam for Alternative SOS 6a**

## J–25 AMMONIA AND NUTRIENTS

The main features of the ammonia–nitrogen simulations are:

- Columbia River concentrations increase downstream of the confluence with the Snake River.
- High winter concentrations discharging from Brownlee Reservoir.
- The water quality standard for ammonia is not exceeded.
- Concentrations do not vary with flow after the first simulation year.
- The greatest lower Snake River concentrations correspond to the deepest and longest drawdowns.

Nitrate–nitrogen and total phosphorus nutrient profiles are also included to show their possible limitations on phytoplankton growth. These main points are demonstrated in Figures J–18 through J–30.

The Snake River raises ammonia, nitrate, and phosphate concentrations in the Columbia River downstream of the confluence during winter, spring and fall. Figures J–19, J–20 and J–22 show the stepped increase of concentrations at the confluence (river mile 340). In the Lower Columbia, Figures J–18 through J–23 show that winter and spring (days 15 and 105) nutrient levels are higher than summer levels (day 227). Although simulated summer ammonia levels are high in Lake Roosevelt (Figure J–18 upstream of river mile 590), and simulated nitrate and phosphate summer levels are high in the Snake River downstream of Brownlee Dam (Figure J–21 and J–23) upstream of river mile 470). Generally, both upper branches of the system show decreasing summer nutrient concentrations downstream to their confluence.

The assumed constant tributary inflow concentrations throughout the entire five–year simulation caused high simulated ammonia levels in late fall (day 349) at Brownlee Dam. This simplifying assumption was made because of the lack of long–term seasonal monitoring of tributaries and mainstem reaches within the Columbia River Basin. The algal concentrations assigned to the tributaries represented algal growth seasons. Brownlee Reservoir had the highest reported phytoplankton cell count of all tributaries in the model. Mortality of the high winter algal biomass that was specified for Brownlee Reservoir inflows resulted in high ammonia concentrations in Brownlee Dam discharges.

Figures J–7, J–9 and J–19 show examples of this situation where 0.3 mg/l ammonia levels are shown in the Hells Canyon reach (river mile 500 to 600). Algal grows during late summer and early fall, until water temperatures in the reservoir drop. Ammonia releases from decay of inflowing algae continue throughout the winter and early spring regardless of tributary water temperatures that inhibit growth. Nitrate levels also are affected in the same manner.

Simulated ammonia concentrations never exceed the water quality standard at the four representative sites. A 0.1 mg/l exceedence level is used here for comparisons. It is below the standard of 0.75 mg/l for typical Columbia River pH (8.0) and temperature (15.0 °C) conditions. The differences between SOS exceedences are more apparent at the 0.1 mg/l level. Simulated ammonia levels at Priest Rapids never exceed 0.1 mg/l, but there was less than 10 percent exceedence at John Day. Exceedences on the lower Snake also increased downstream.

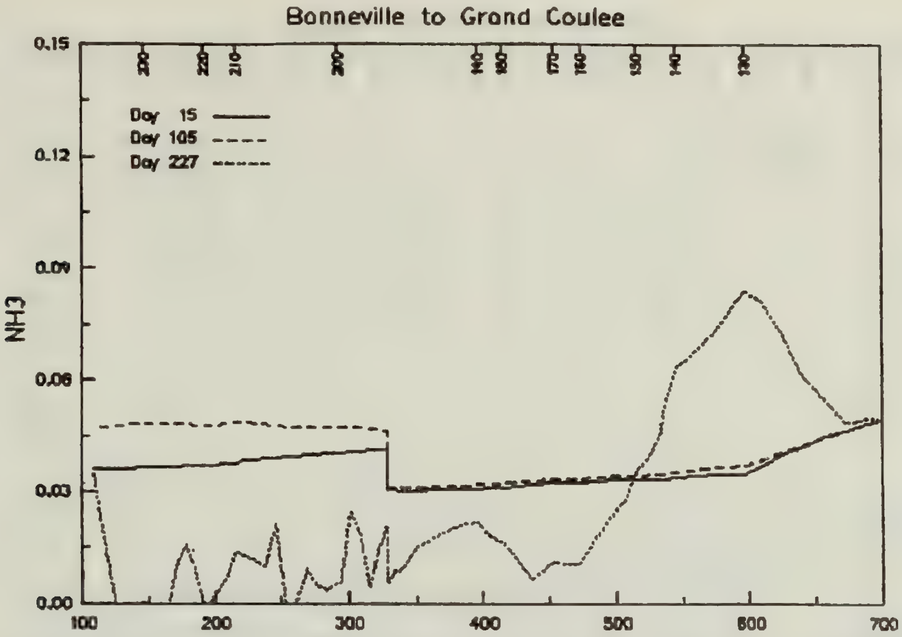


**Figure J–18.** **Ammonia Concentrations (mg/l) from Bonneville to Grand Coulee, Average Flow, Year 1, Alternative SOS 2a**

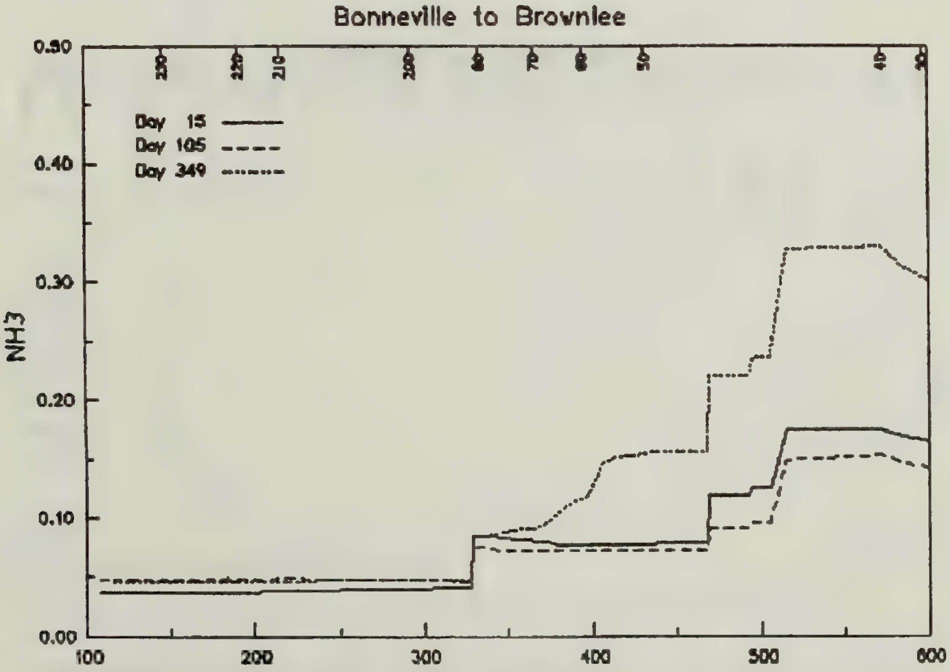


**Figure J–19.** **Ammonia Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 2a**

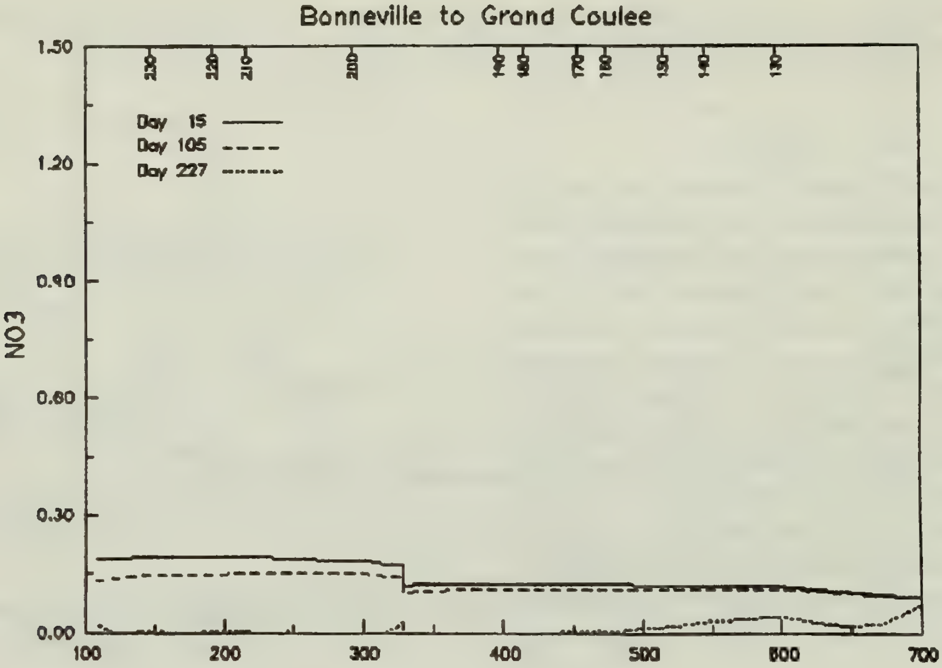


**Figure J–20.** **Nitrate Concentrations (mg/l) from Bonneville to Grand Coulee, Average Flow, Year 1, Alternative SOS 2a**

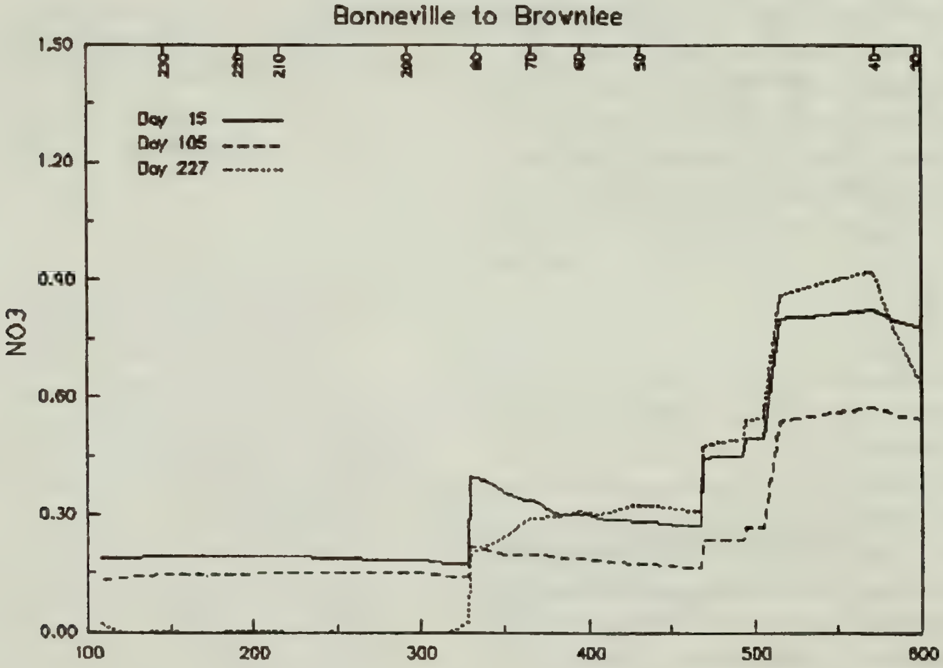


**Figure J–21.** **Nitrate Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 2a**

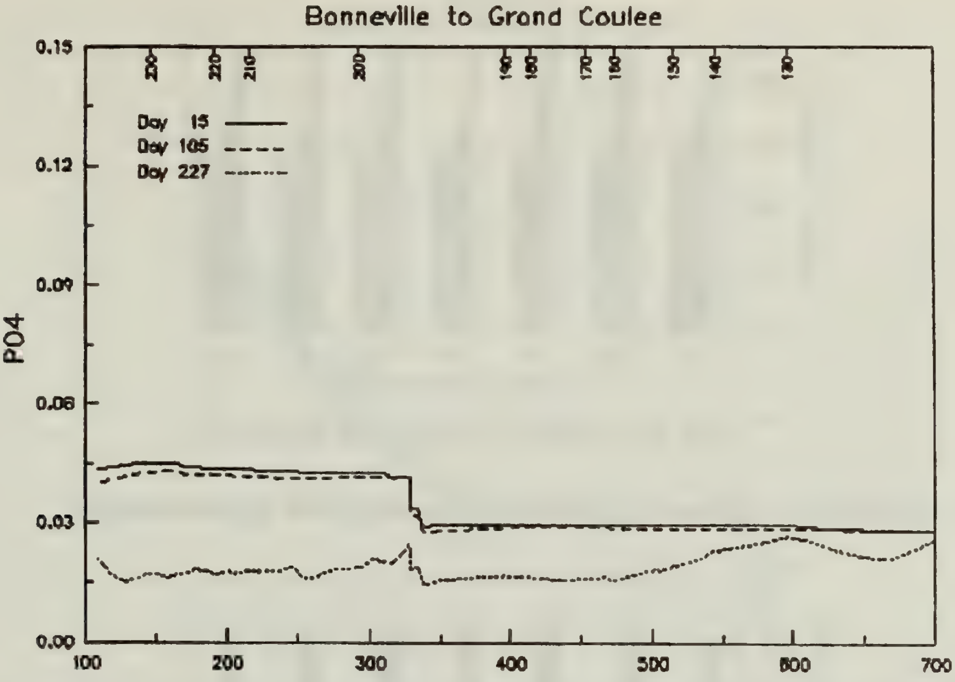


Figure J–22. Phosphate Concentrations (mg/l) from Bonneville to Grand Coulee, Average Flow, Year 1, Alternative SOS 2a

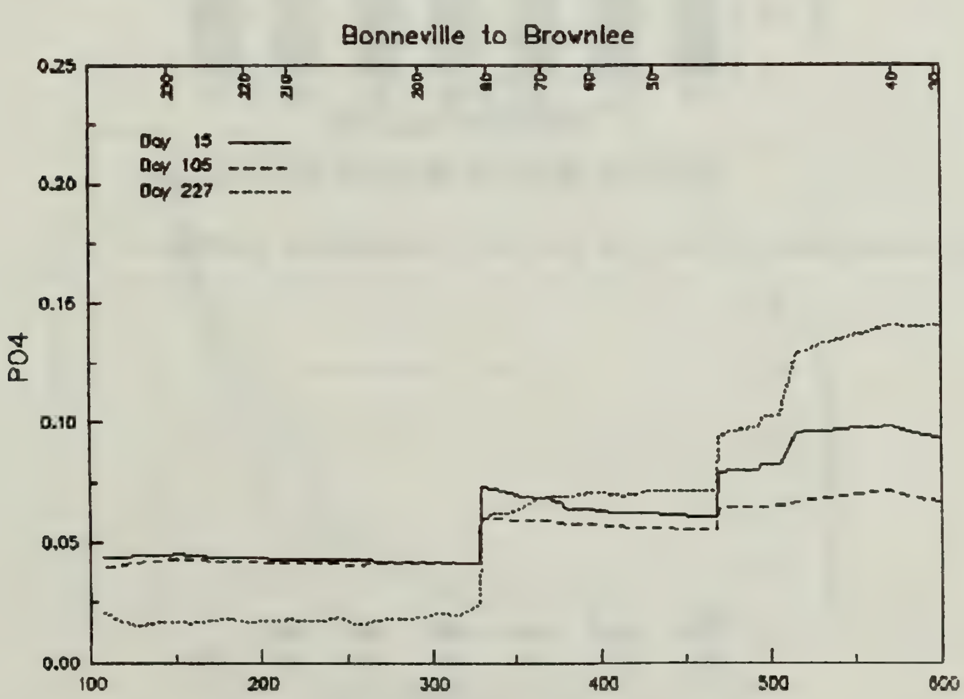


Figure J–23. Phosphate Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 2a

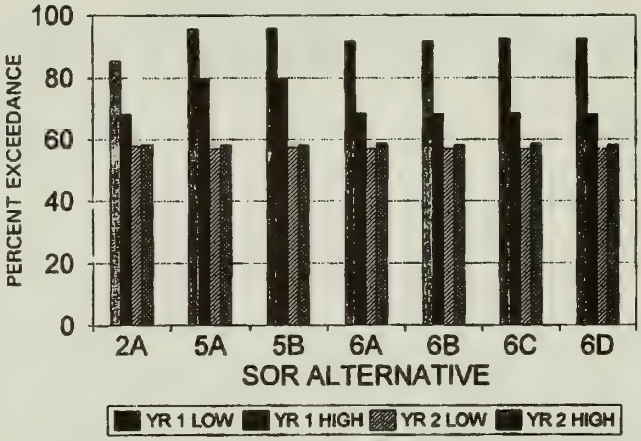


Figure J–24. Exceedence in Year 1 & 2 0.1 mg/l Ammonia at Lower Granite

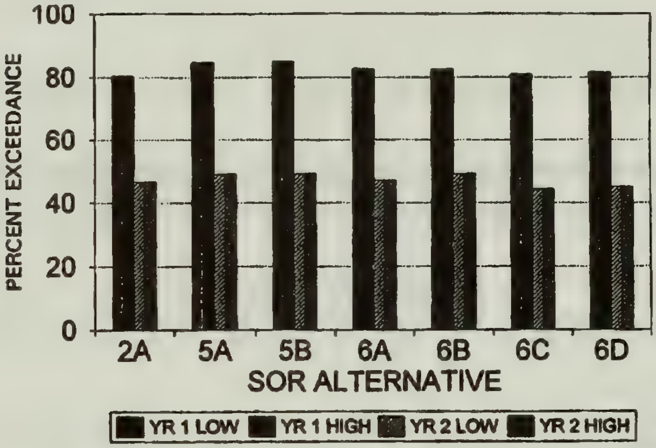


Figure J–25. Exceedence in Year 1 & 2 0.1 mg/l Ammonia at Ice Harbor

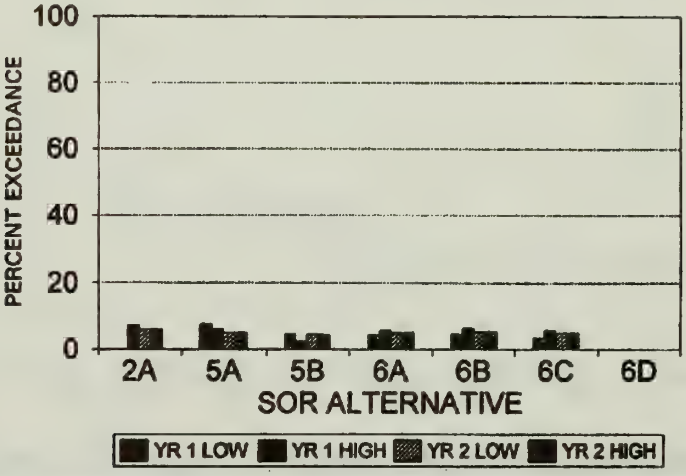


Figure J–26. Exceedence in Year 1 & 2 0.1 mg/l Ammonia at John Day

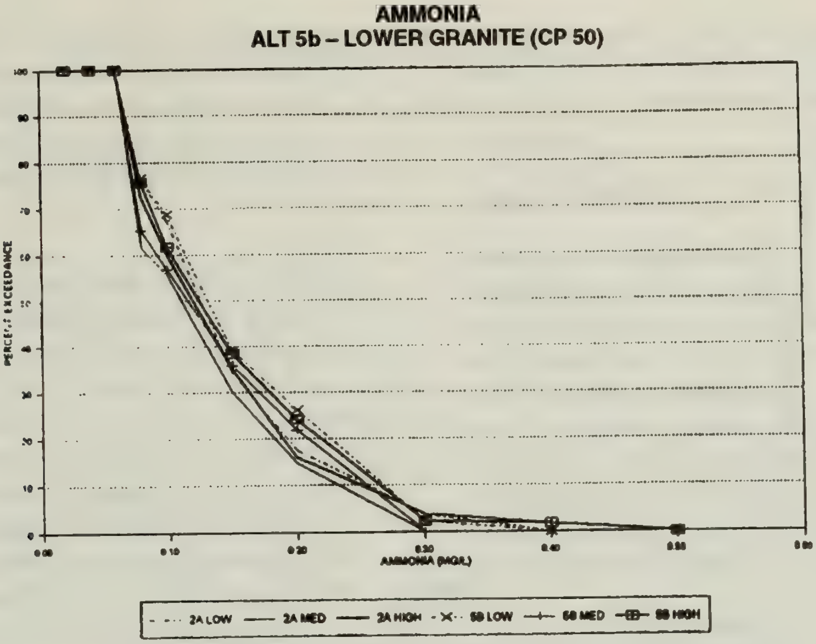


**Figure J–27. 5–Year Exceedence for Ammonia at Lower Granite Dam for Alternative SOS 5b**

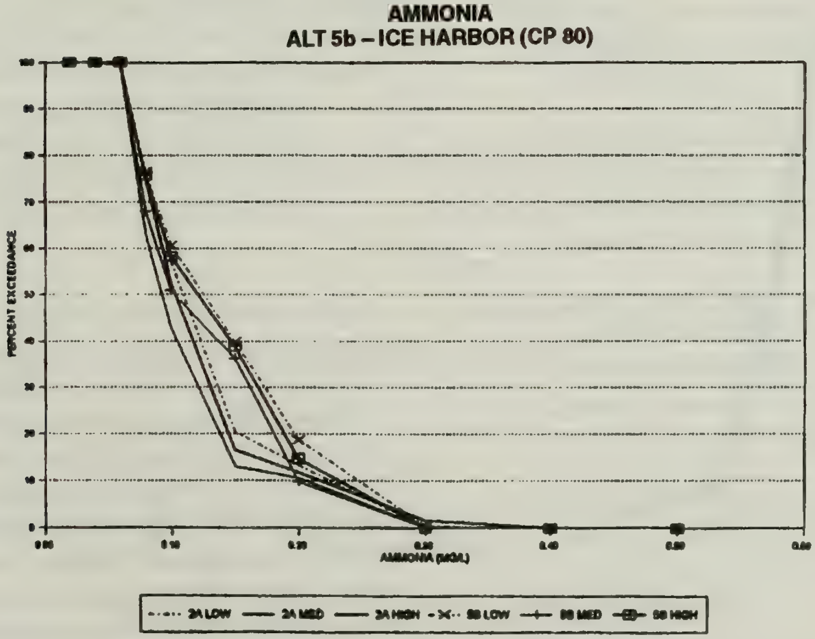


**Figure J–28. 5–Year Exceedence for Ammonia at Ice Harbor Dam for Alternative SOS 5b**

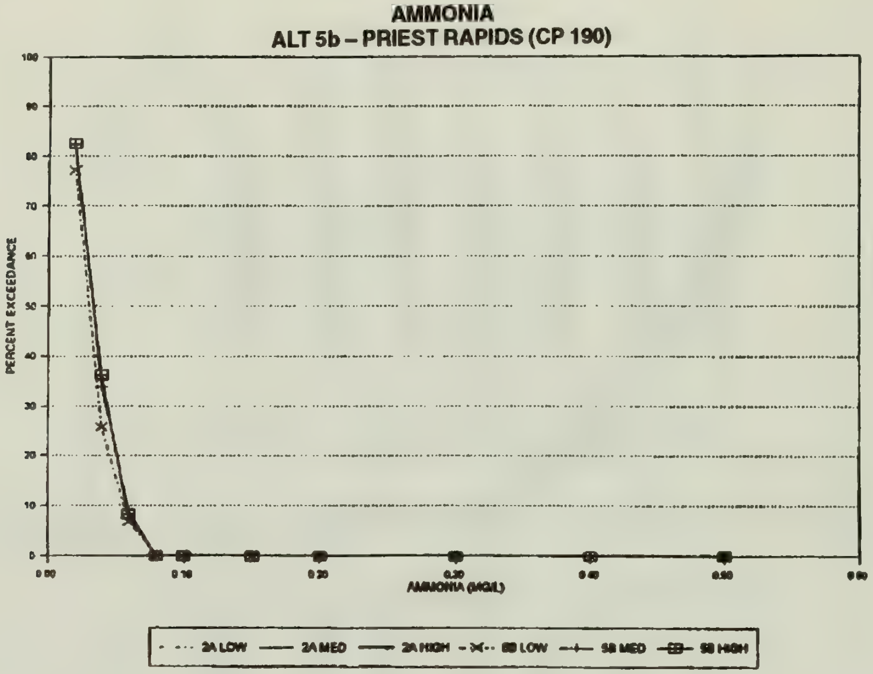


**Figure J–29.** 5–Year Exceedence for Ammonia at Priest Rapids Dam for Alternative SOS 5b

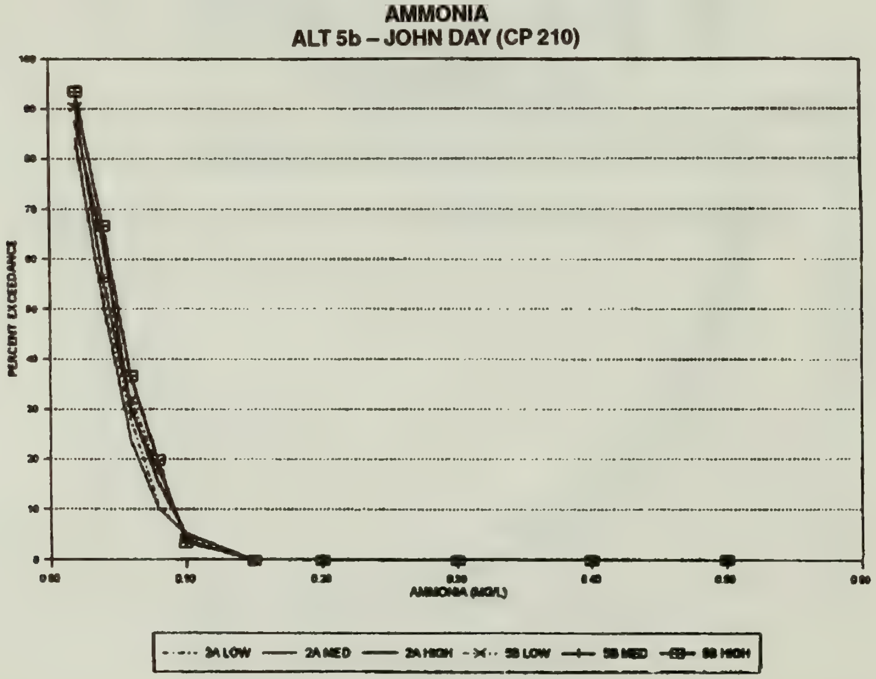


**Figure J–30.** 5–Year Exceedence for Ammonia at John Day Dam for Alternative SOS 5b

Simulated ammonia concentrations generally did not vary with flow, except at Lower Granite during year one. Figure J–24 shows about a difference of 15–20 percent in 0.1 mg/l ammonia exceedence between high and low year one flows at Lower Granite.

Higher exceedence at low flows indicates that dilution influences ammonia concentration at Lower Granite Dam. Figures J–25 and J–26 show that this is not the case at Ice Harbor and John Day. Year two showed the more typical case where flow differences were minor. On the Snake River, there was up to a 35 percent difference between year one and year two exceedence for all SOSs. On the Columbia River, Priest Rapids never exceeded 0.1 mg/l, and John Day only had a maximum of 7 percent exceedence for both year one and two.

SOS 5b resulted in the greatest simulated ammonia exceedences on the Snake River, but only during year one. Most of the other drawdown SOSs had about the same exceedence as the base case. Figures J–24 and J–25 shows SOS 5b exceedence of 0.1 mg/l ammonia is greater than the other SOSs, but not by much. The greatest difference was during high flows at Lower Granite, even though the overall greatest exceedence was during first year low flows. The greatest long–term exceedence difference between the base case and SOS 5b is shown in Figure J–28. SOS 5b exceedences at Ice Harbor Dam during high flows are at most 35 percent greater than SOS 2a.

The simulation of nutrients indicates that nitrogen nutrients limit phytoplankton growth. Summer (day 227) ammonia concentrations increase downstream through Lake Roosevelt (river miles 700 through 600), then decrease steadily towards river mile 440. Figure J–18 shows this pattern which is also typical of all the drawdown alternatives. The concentration downstream of river mile 440 fluctuates at low levels and occasionally approaches zero. Summer nitrate–nitrogen concentrations in the Columbia River, as shown in Figure J–20, also approach zero in some reaches. Phosphorus concentrations shown in Figures J–22 and J–23 never reach zero. Near zero simulated ammonia and nitrate nitrogen concentrations in the Lower Columbia indicate that phytoplankton growth is nitrogen–limited there during the summer.

## J–26 SEDIMENT

A high priority objective of this modeling effort is to predict and evaluate sediment–related impacts on water quality that may result from the proposed river system operations. The integration of results from the HEC–6 modeling of current and proposed SOR drawdown operations of Lower Granite Reservoir (Corps, 1993), and the shoreline erosion analysis (Attachment A) has a major influence on the results of this HEC–5Q water quality model. The main features of the sediment simulations are:

- Silt is representative of the total sediment because of its potentially massive response to drawdown SOSs, in terms of both transport volume and distance, relative to sand and clay transport.
- Suspended sediment (silt) concentration is strongly related to turbidity.
- Natural river drawdown should create the greatest silt concentrations and turbidities of all the SOSs.
- The first year of drawdown operations should create the greatest silt concentrations, then reduce significantly in later years, barring unusual flow and wind conditions.
- Lower Snake River reservoir beds should be scoured down to pre–project thalwegs, in re–created free–flowing reaches, within five years of repeated drawdown (also barring unusual flow and wind conditions).
- SOS 5 should cause extensive silt accumulation in Lake Wallula, but SOS 6 should transport scoured silts only as far as the next downstream pool.
- Additional long–term sediment accumulations should only come from reservoir shoreline erosion during drawdowns.

The HEC−5Q simulated silt concentration and total sediment accumulation patterns in the Lower Snake and Columbia Rivers are shown in Figures J−31 through J−43.

### J–26.1 Silt, Sediment and Turbidity

Sediment transport is an important water quality parameter to the SOR because it is closely related to turbidity. Silt concentrations reported here represent only one component of the total sediment load. Sediment is generally classified by its grain size. Sand and silt sediment grain−sizes were also included in the HEC−5Q model. Their results are not presented here, because the simulations resulted in wider variations in silt transport than clay or sand in response to the SOSs. Less clay (finer grained than silt) exists in the reservoir beds, and it does not settle out as fast as silt. So clay tends not to have the high concentration peaks like silt, and stays at more uniform levels. Large quantities of sand exist in the beds, but sand settles much faster than silt.

Sand concentrations tend to have high peaks like silt, but they do not translate downstream nearly as far as silt.

The silt component of sediments in the HEC−5Q model is used here to estimate turbidity. The Corps provided sediment and turbidity data from dredging operations monitoring. The turbidity−sediment correlation used here was formulated from this data. Turbidity is related to sediment by multiplying the simulated silt concentrations by 1.331, then raising the product to the 0.741 power. Silt concentration is assumed to be 85 percent of the suspended sediment concentration. Therefore, 50 mg/l silt corresponds to a turbidity of approximately 21 NTUs; and 500 mg/l corresponds to about 118 NTUs. Figure J−31 shows this correlation.

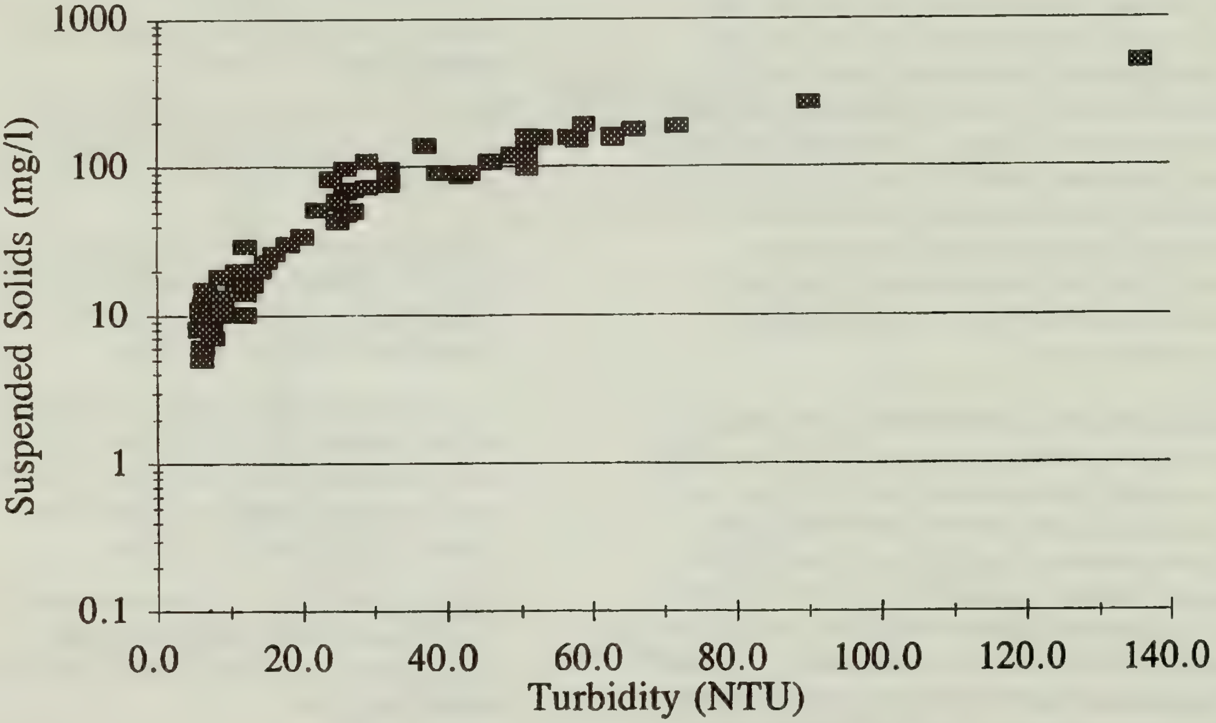


**Figure J–31. Correlation Between Snake River Suspended Sediment and Turbidity**

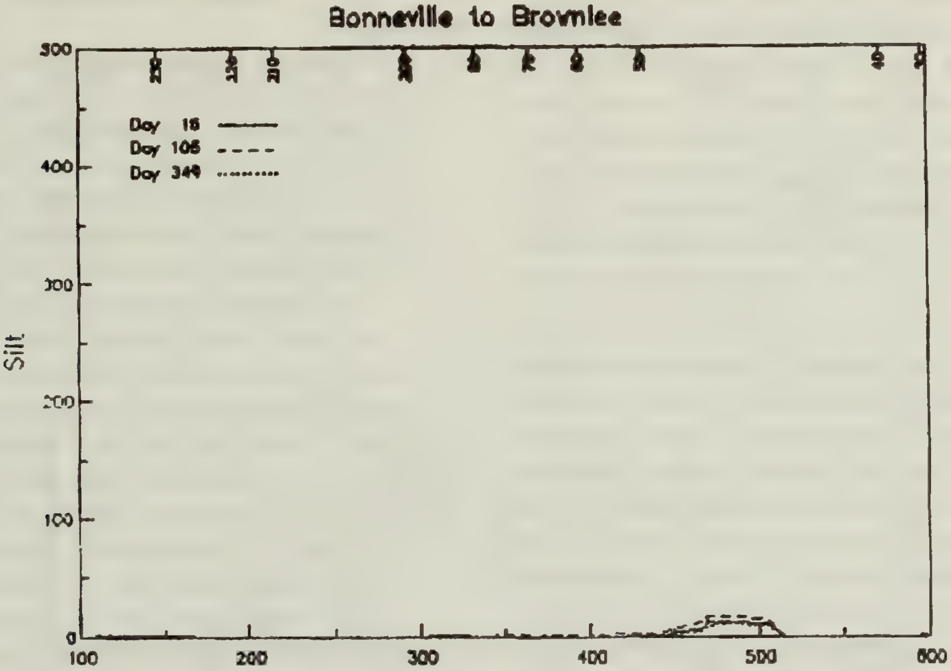


**Figure J–32.** Silt Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 2a

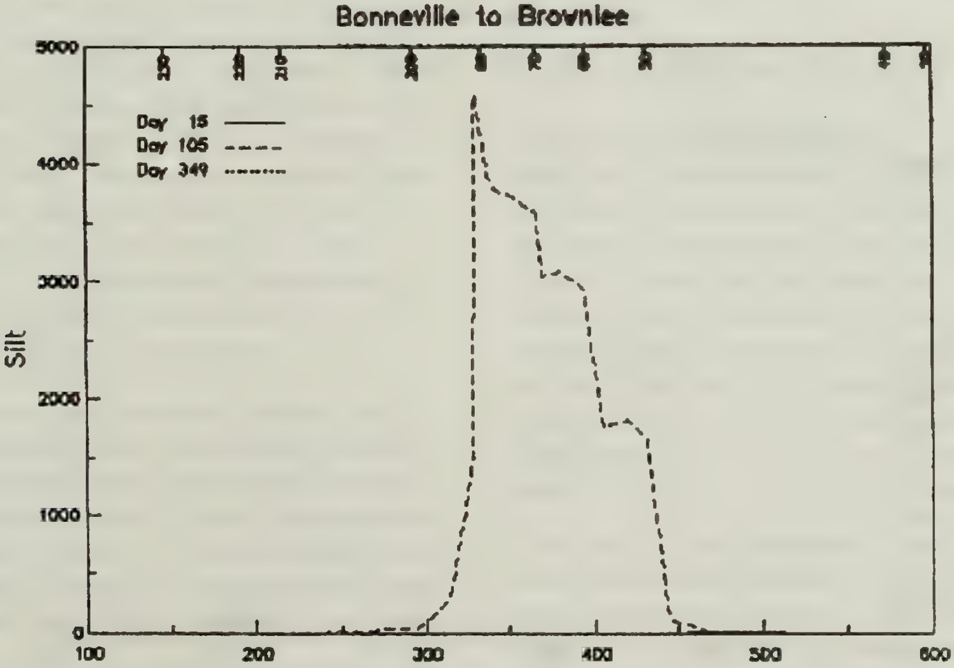


**Figure J–33.** Silt Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 5a

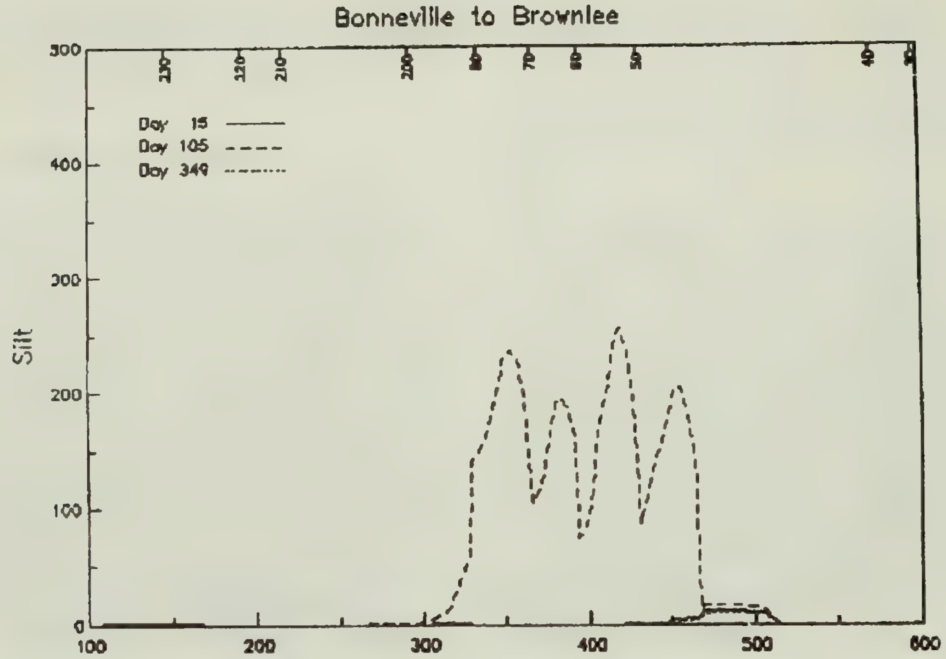


**Figure J–34.** Silt Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 6a

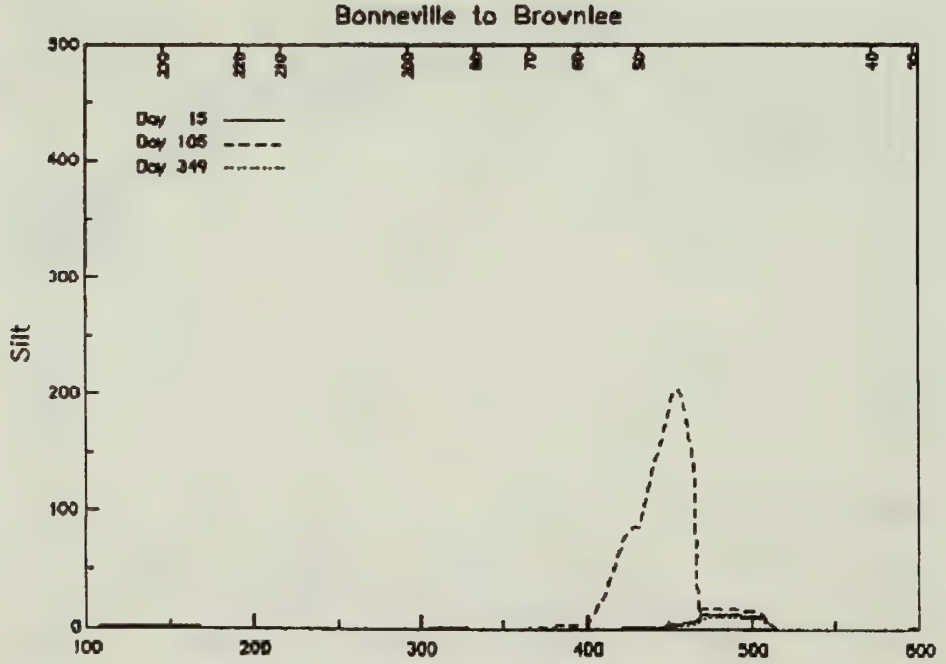


**Figure J–35.** Silt Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 6c

### J–26.2 Silt Concentration Profiles

Simulated silt concentration and total sediment accumulation longitudinal profiles of the system show the main characteristics of sediment transport that could result from the proposed SOSs. Figures J–32 and J–44 show the simulated current operation silt concentrations and total sediment accumulations in the Bonneville to Brownlee branch. The day–349 profile in Figures J–44 through J–49 show kilograms of total sediment accumulation over a square meter of stream bed within a simulation year. The simulated concentration and accumulation for this base case are negligible, but the patterns show how the HEC–6/HEC–5Q model procedures are working. The only noticeable concentrations in Figure J–32 are near river mile 500. Here, silt loads from tributary inflows are carried downstream. Figure J–44 shows where these loads are deposited. Minor lower Snake River reservoir sediment scour and deposition are also shown in these figures.

The silt concentrations that could result from drawdown operations are up to two orders of magnitude greater than the base case. Figures J–33 through J–35 show the first simulation year concentration profiles for SOS 5a, 6a, and 6c, respectively. The day–105 profile corresponds to April 15th the day that maximum drawdown would be reached for all the drawdown SOSs. The day that maximum drawdown is reached should have one of the greatest turbidities during the entire drawdown period (Corps, 1992c). The maximum silt concentration shown in these figures is about 4,500 mg/l, at Ice Harbor Dam, for SOS 5a, on day 105.

The full drawdown may create the greatest silt concentrations, but the 33–foot drawdown operation simulations also result in high silt concentrations. A maximum of about 250 mg/l silt concentration in the water column is expected to result from SOS 6. Figures J–34 and J–35 show concentration profile peaks at each of the drawn down reservoirs.

Partial drawdowns settle more sediment out of the water column than full drawdowns. SOS 5 should scour and transport silt continually through the entire lower Snake River, then deposit most of its load in the Columbia River just downstream of the confluence. SOSs 6a and 6b should scour sediment beds at the head of all the lower Snake River reservoirs, then deposit most of its load in the next partially drawn down pool downstream. Figure J–35 shows that the silt scoured from lower Granite Reservoir should completely settle out before Little Goose Dam.

The first year of drawdown should create the greatest silt concentrations. Figures J–36, J–37 and J–38 show the silt concentration profiles for later simulation years. The maximum expected concentration is about 200 mg/l for SOS 5a at Ice Harbor Dam, during the second year, as shown in Figure J–36. Maximum SOS 6 concentrations should drop to about 50 mg/l within the drawn down reservoirs, as shown in Figure J–37. By the fifth year, the maximum silt concentration resulting from drawdown SOSs should be below 50 mg/l. Figure J–38 shows the simulated SOS 5a silt profile. Eroded reservoir bank sediments may continue to be transported during repeated annual drawdowns, whereas channel scouring may discontinue within five years.

### J–26.3 Silt Exceedence Duration

In terms of exceedence, Figures J–39 and J–40 show that in the Snake River, the SOS 5a and 5b silt concentrations should be greater than 50 mg/l for about 20 percent of the time (just over 2 months), during first two years. At Lower Granite Dam, the highest silt concentrations are expected during high–flow conditions. Silt scour is expected to drop 20 percent in the second year at Lower Granite Dam. At Ice Harbor Dam, the influence of flow diminishes, but the silt exceedences still are expected to drop slightly in the second year.

Over the five–year simulation period, elevated silt concentrations are expected to endure more during low–flow periods than during high flow, for SOS 5. Figure J–41 shows that the low–flow exceedence curve is lower than the high–flow exceedence curve at low silt concentrations, but not at high concentrations. Exceedence of higher silt concentrations may be greater for low–flow conditions, but the exceedence difference at these levels between high and low–flow conditions is small. This indicates that the accumulated sediments in Lower Granite Reservoir scour out within the five–year simulation period for both flow conditions. At Lower Granite Dam, higher, yet shorter–duration sediment transport is expected under high–flow conditions, and lower, yet longer–duration sediment transport is expected under low–flow conditions.

Sediments scoured from upstream reservoir beds may accumulate to increase durations of elevated silt concentrations at Ice Harbor Dam. Figures J–41 and J–42 show that the percent exceedence of 75 mg/l to 500 mg/l silt is greater at Ice Harbor, than at Lower Granite, for SOS 5. Figures J–41 and J–43 show that the percent exceedence of 50 mg/l to 150 mg/l silt is also greater at Ice Harbor for SOS 6a and 6b.

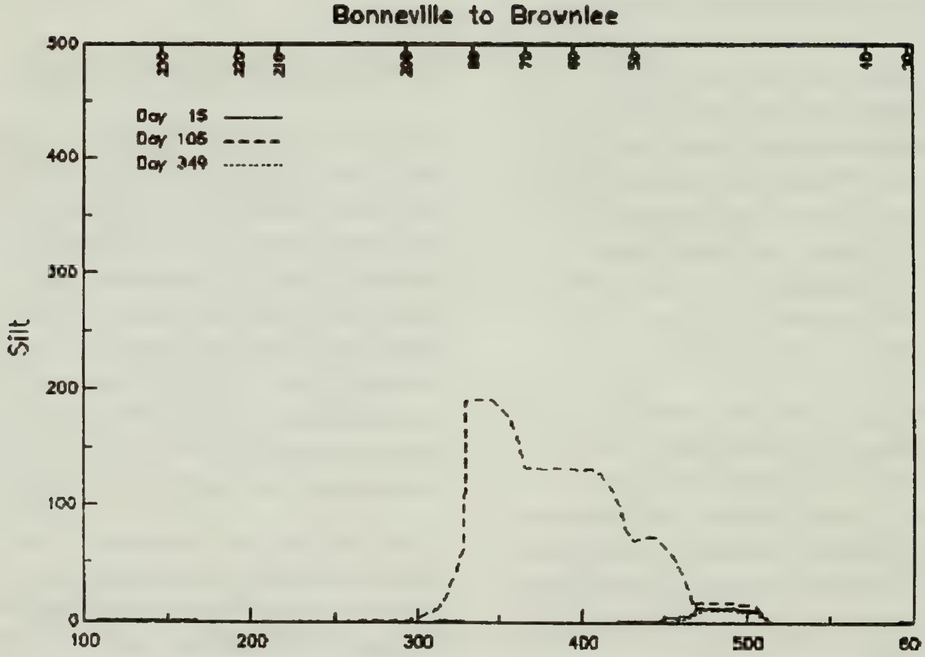


**Figure J–36. Silt Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 2, Alternative SOS 5a**

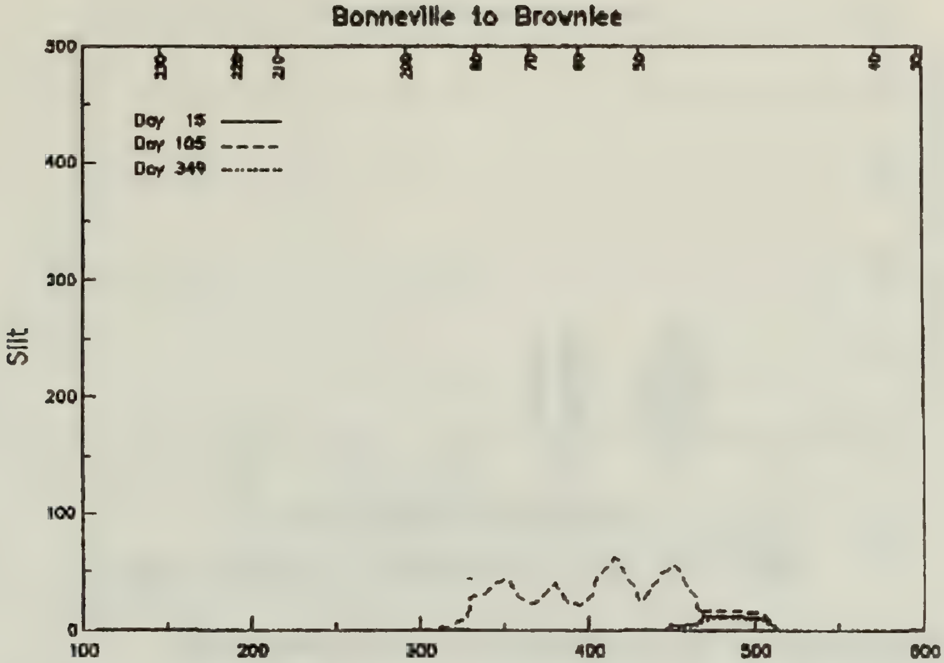


Figure J–37. Silt Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 2, Alternative SOS 6a

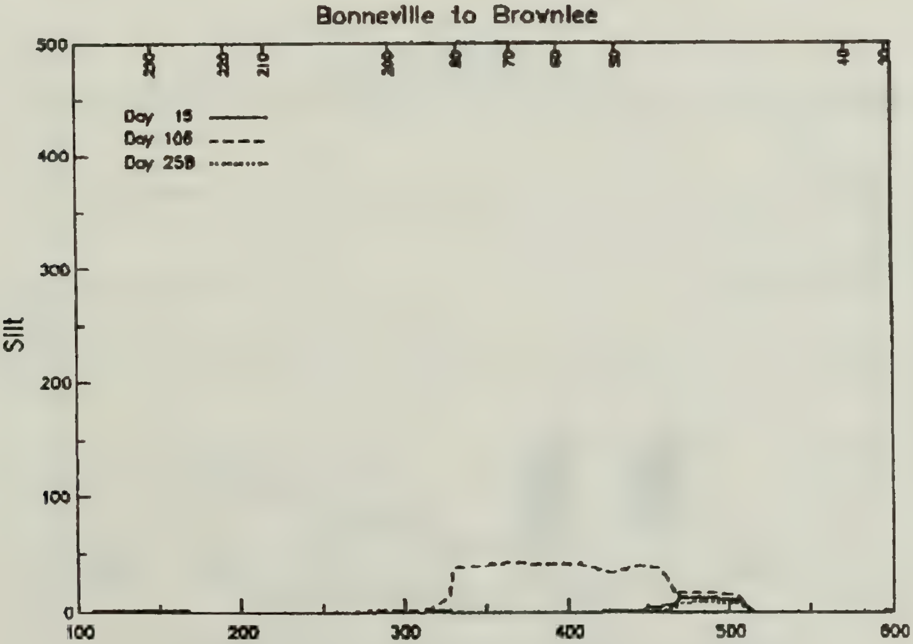


Figure J–38. Silt Concentrations (mg/l) from Bonneville to Brownlee, Average Flow, Year 5, Alternative SOS 5a

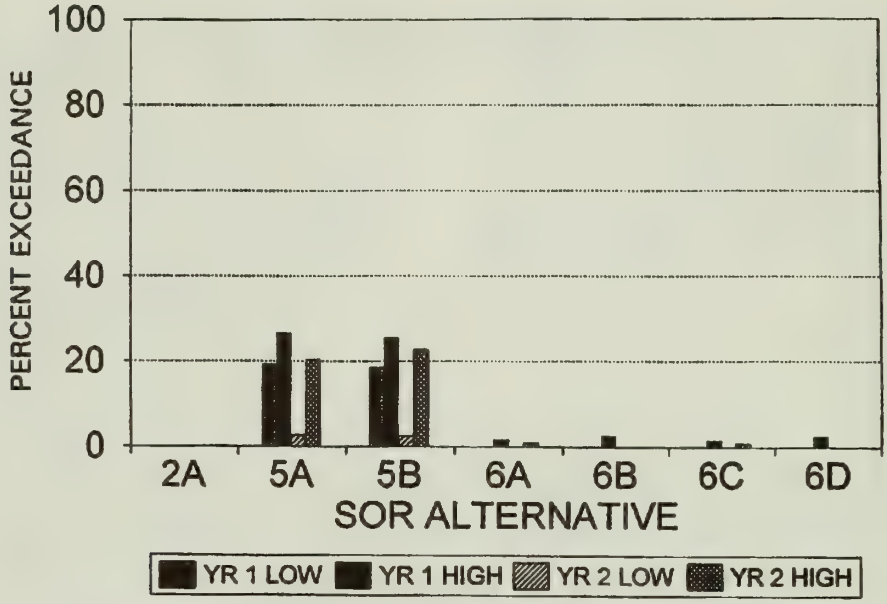


**Figure J–39.** **Exceedence in Year 1 & 2 50 mg/l Silt at Lower Granite**

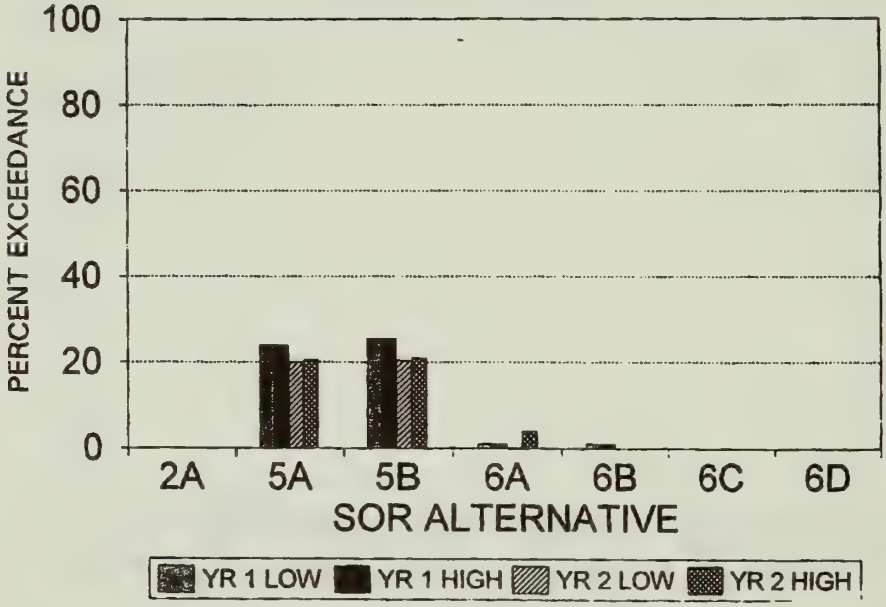


**Figure J–40.** **Exceedence in Year 1 & 2 50 mg/l Silt at Ice Harbor**

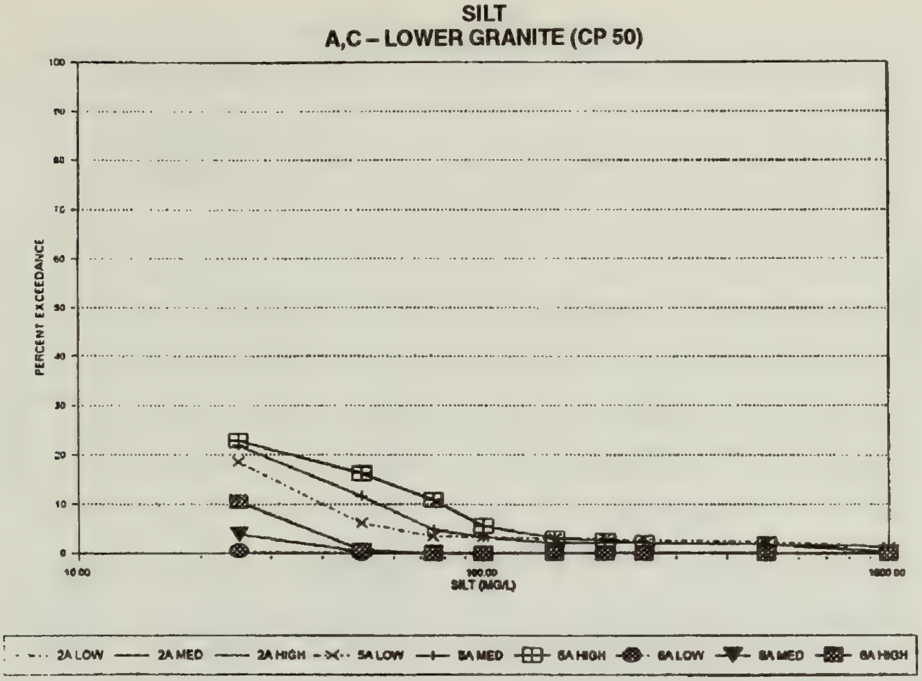


**Figure J–41.** 5–Year Exceedence for Silt at Lower Granite Dam for Alternative SOS 5a and SOS 6a

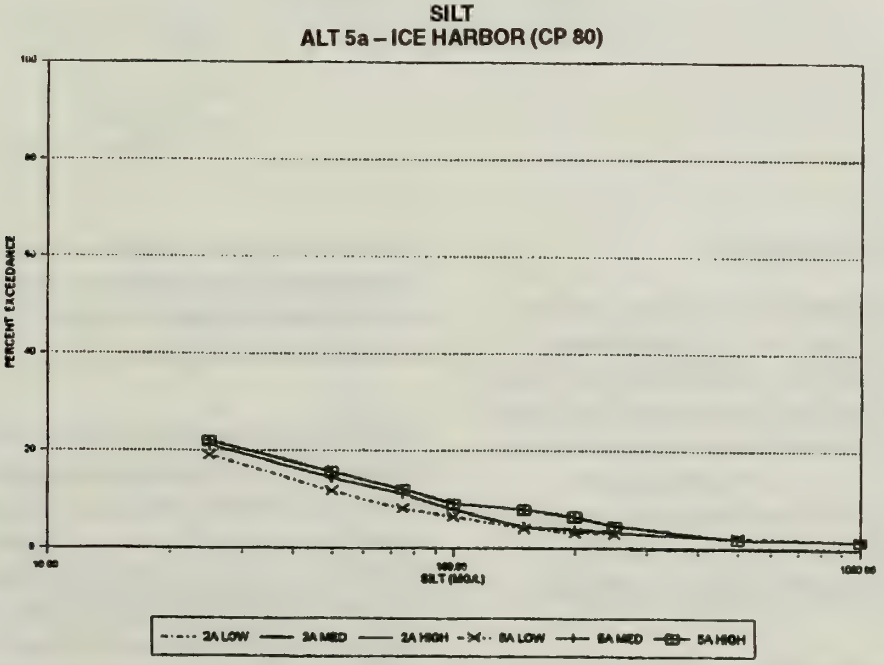


**Figure J–42.** 5–Year Exceedence for Silt at Ice Harbor Dam for Alternative SOS 5a

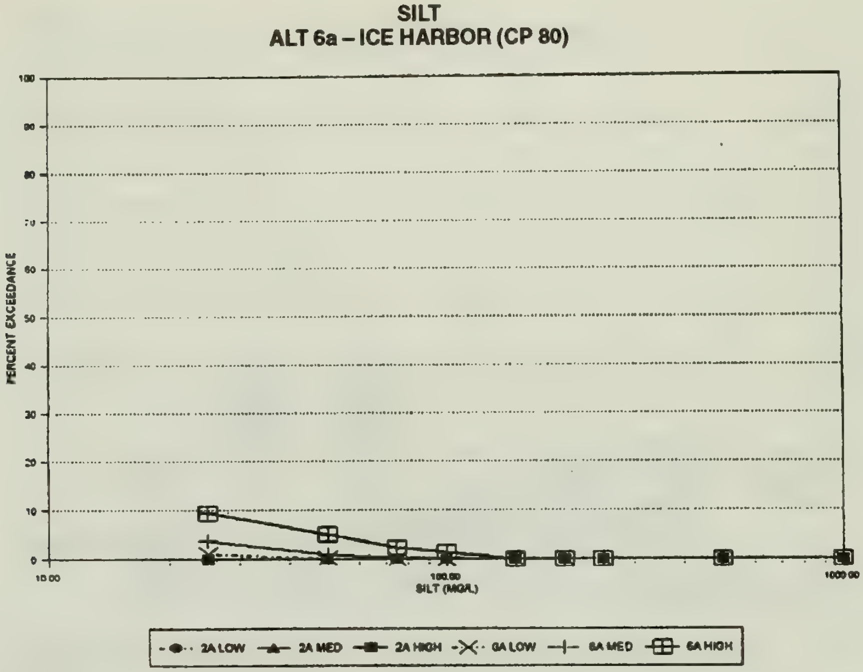


Figure J–43. 5–Year Exceedence for Silt at Ice Harbor Dam for Alternative SOS 5a

### J–26.4 Sediment Accumulation

The sediment that is expected to be transported out of the Snake River during drawdown operations should be deposited upstream of McNary Dam. The simulations indicate that SOS 5a and SOS 5b should result in the greatest sediment accumulation in Lake Wallula. Figures J–45 and J–46 show the first simulation year's total sediment accumulation below the confluence (river mile 324.2). Both SOS 5 options accumulate a maximum of about 250 kg/m$^2$ of sediment here.

First year SOS 6b sediment accumulation in the Columbia River is shown in Figure J–47. The accumulation is less than 10 kg/m$^2$ at the confluence. This accumulation is within the range of simulated accumulations in the Columbia River downstream of the confluences of Mid–Columbia tributaries (between river miles 450 and 550).

Columbia River sediment accumulation after two years should not be significant for SOS 6, but SOS 5 simulations indicate elevated accumulation here should persist up to five years. Figures J–48 and J–49 show second and fifth year simulated annual sediment accumulations for SOS 5b. The second year simulated accumulation of about 35 kg/m$^2$ is only 14 percent of the first year accumulation. By simulation year five, the accumulation is reduced to that of normal tributary loading.

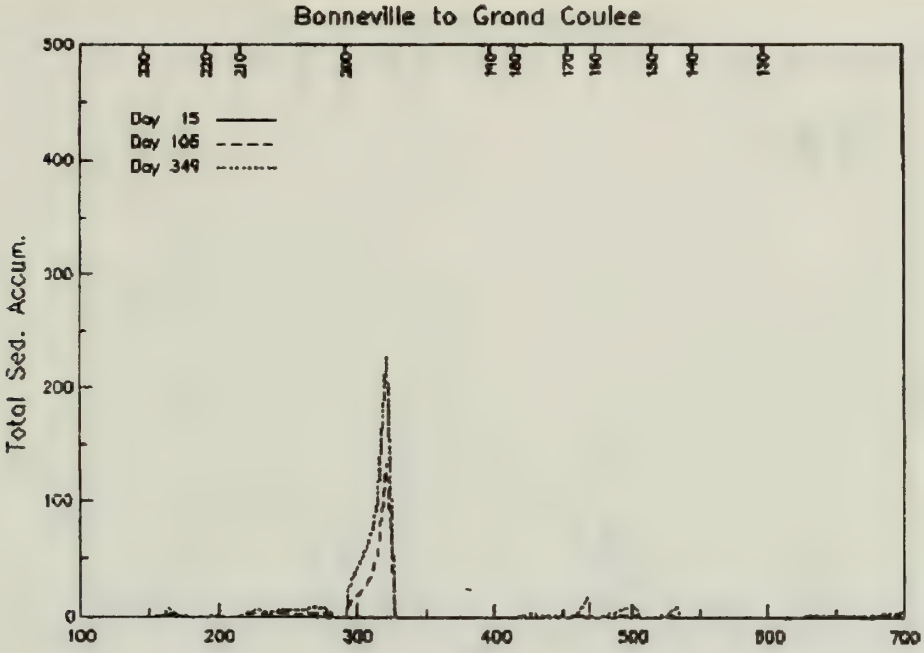


**Figure J–44.** **Total Sediment Accumulations (kg/m$^2$) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 2a**

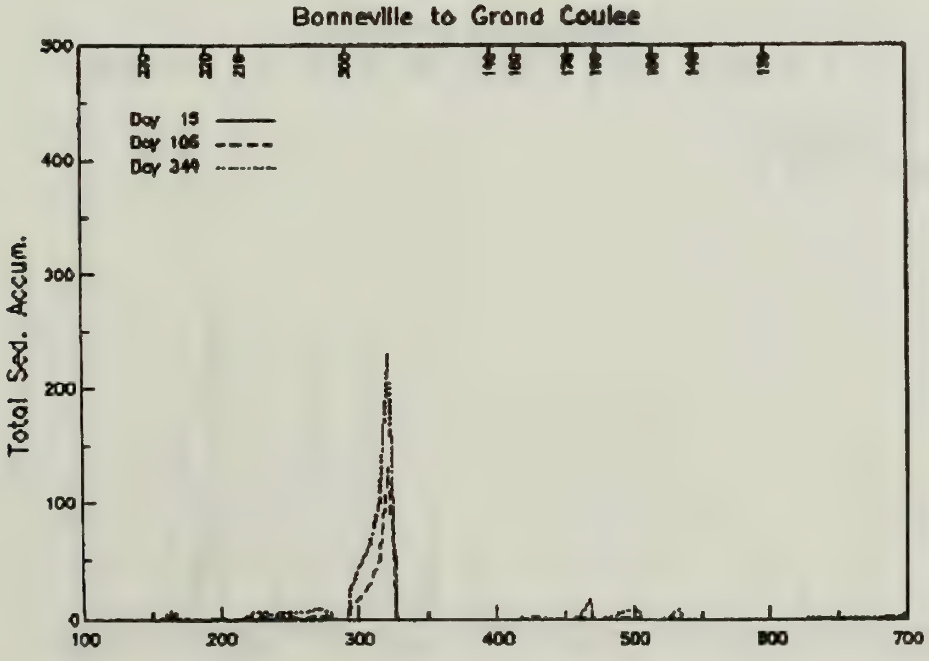


**Figure J–45.** **Total Sediment Accumulations (kg/m$^2$) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 5a**

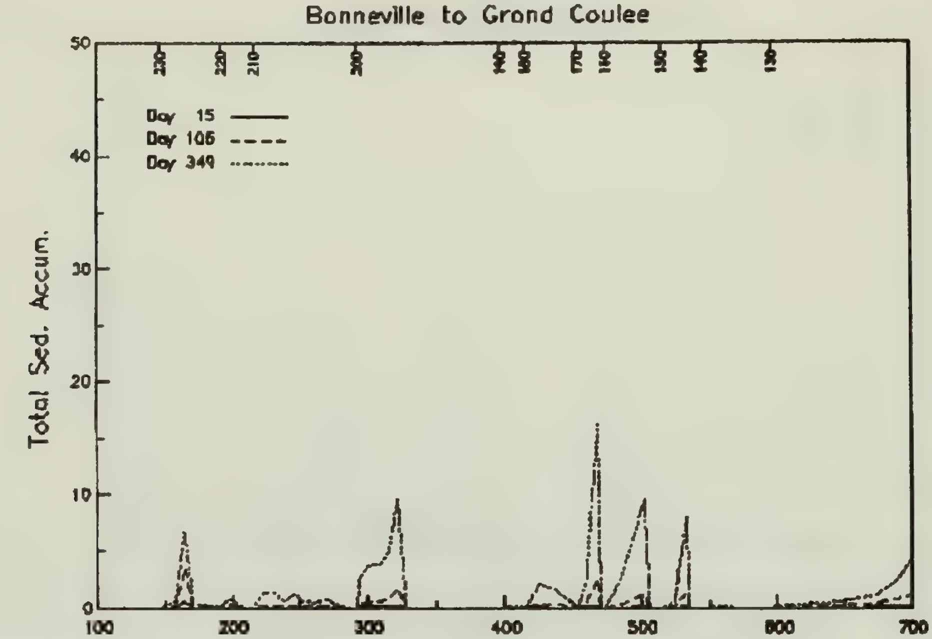


Figure J–46. Total Sediment Accumulations (kg/m$^2$) from Bonneville to Grand Coulee, Average Flow, Year 1, Alternative SOS 5b

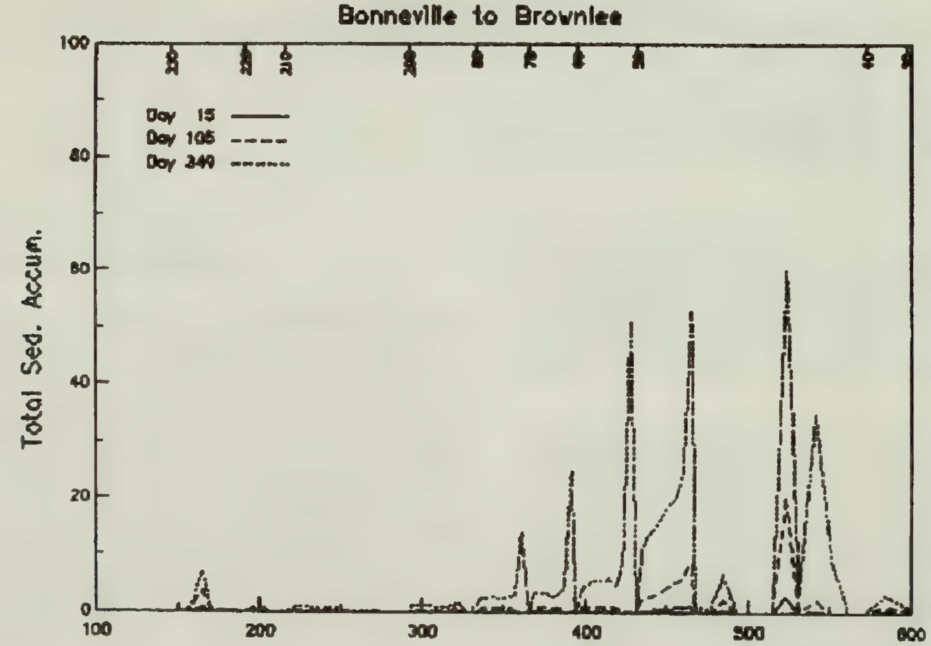


Figure J–47. Total Sediment Accumulations (kg/m$^2$) from Bonneville to Grand Coulee, Average Flow, Year 1, Alternative SOS 6b

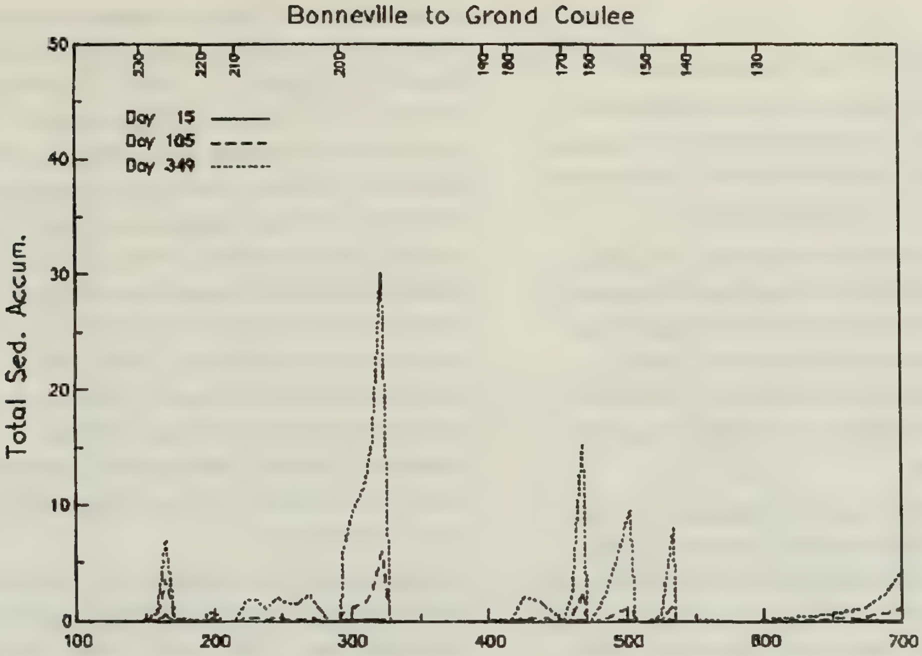


Figure J–48. Total Sediment Accumulations (kg/m$^2$) from Bonneville to Grand Coulee, Average Flow, Year 2, Alternative SOS 5b

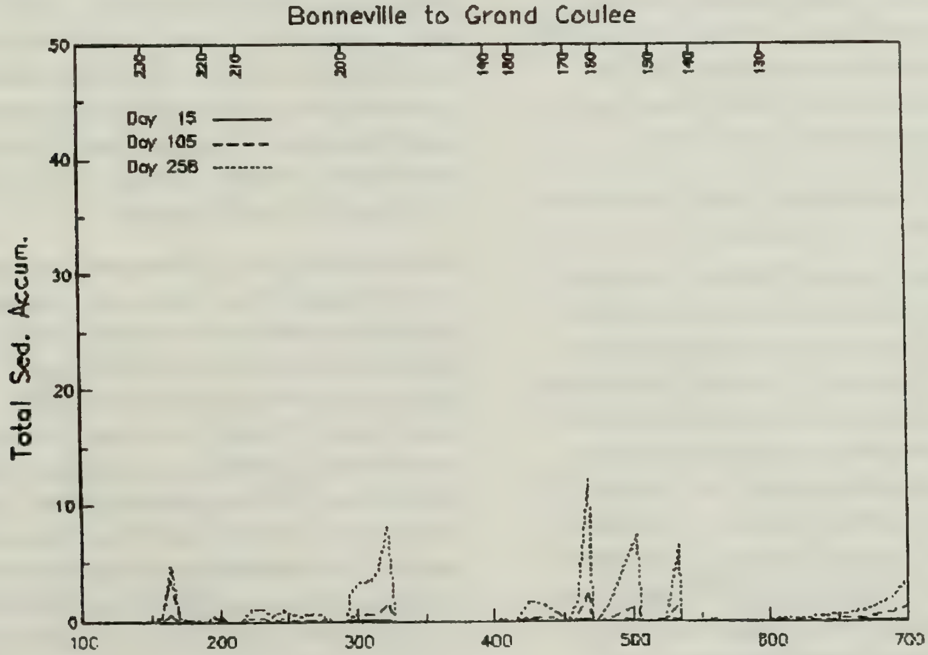


Figure J–49. Total Sediment Accumulations (kg/m$^2$) from Bonneville to Grand Coulee, Average Flow, Year 5 Alternative SOS 5b

## J–27 LEAD

The main features of the lead simulations are:

- Lead concentration responses to drawdown are similar to those of silt concentrations, because of the presence of lead sorbed to sediments in Lower Snake River reservoir beds.
- The greatest simulated total lead concentration of 150 ug/l occur in the Snake River near its mouth, around the April 15th drawdown target date, during the first year of SOS 5 drawdown, but the corresponding dissolved lead concentration is about three orders of magnitude less.
- Total lead concentrations upstream of Lower Granite Reservoir are not exceeded in the lower Snake River after the first year of drawdowns, but unlike current operations, the lead from upstream sources is transported downstream of Lower Granite Dam.
- Lead transported by the Snake River should accumulate in Lake Wallula on the Columbia River only under SOS 5.
- The 25 ug/l water quality standard for lead should be exceeded on an average of up to 20 percent of the time on an annual basis, at Lower Granite and Ice Harbor Dams, during the first 5 years of SOS 5 and SOS 6.

Simulation results demonstrating these main points are plotted in Figures J–50 through J–71.

Snake River concentrations of lead and silt respond similarly to the proposed drawdown SOSs, because the main source of lead is the reservoir sediment beds. Figures J–50 through J–58 show the longitudinal profiles of simulated total and dissolved lead concentrations in the lower Snake and Columbia Rivers. The non–drawdown profile in Figure J–50 shows the lead loading from Snake River tributaries upstream of Lower Granite Reservoir. The downstream concentration reduction of lead from these sources is likely due to lead sorbed to sediment settling out of the lower Snake reservoirs. This storage of lead in the reservoir bed sediments should be resuspended into the water column once again by scour resulting from the proposed drawdown SOSs.

As with silt, the highest simulated lead concentrations result from the proposed natural river drawdown SOS. Figure J–51 and J–52 show the total and dissolved lead concentrations in the Snake River for the first simulation year. The day 105 profile shows the probable maximum concentrations. The concentration rises sharply above the tributary loading levels in Lower Granite Reservoir, then increases gradually downstream through the lower Snake River. In the Columbia River just downstream of the confluence at river mile 324, the concentration drops sharply. This drop is due to sediment deposition in Lake Wallula. The maximum simulated total and dissolved lead concentration of about 150 ug/l and 0.095 ug/l, respectively, is reached at Ice Harbor Dam.

The simulated lead concentration profiles for SOS 6 show the same scour and settling pattern as silt concentrations. Figures J–53 and J–54 show total lead concentration peaking at each drawn down reservoir. In Figure J–53, SOS 6a simulations show elevated total lead concentrations reach into Lake Wallula (river mile 300 to 324). In Figure J–54, SOS 6c simulations show elevated lead total concentrations reach into Lake Bryan (river mile 375 to 400). Figure J–55 shows dissolved lead concentration profiles for SOS 6c. Elevated dissolved lead concentrations extend further downstream, but at much lower levels than total lead. The dissolved lead profiles are more similar to clay profiles (see Attachment C) in this respect.

After the first year of drawdown, simulated lead concentrations do not have peak concentrations greater than the tributary loading levels upstream of Lower Granite Reservoir, but the rate of downstream concentration reduction is lower. Figures J–56, J–57 and J–58 show the total lead concentration profiles for second year drawdown simulations. The free–flowing stream reaches created by drawdown should keep some sediments and lead in suspension as far downstream as the next reservoir. The second year simulations show that additional lead is still being scoured from the reservoir beds. The SOS 5a profile shown in Figure J–56 shows near constant total lead throughout the Lower Snake River. In this case, scouring and settling of leaded sediments are about equal.

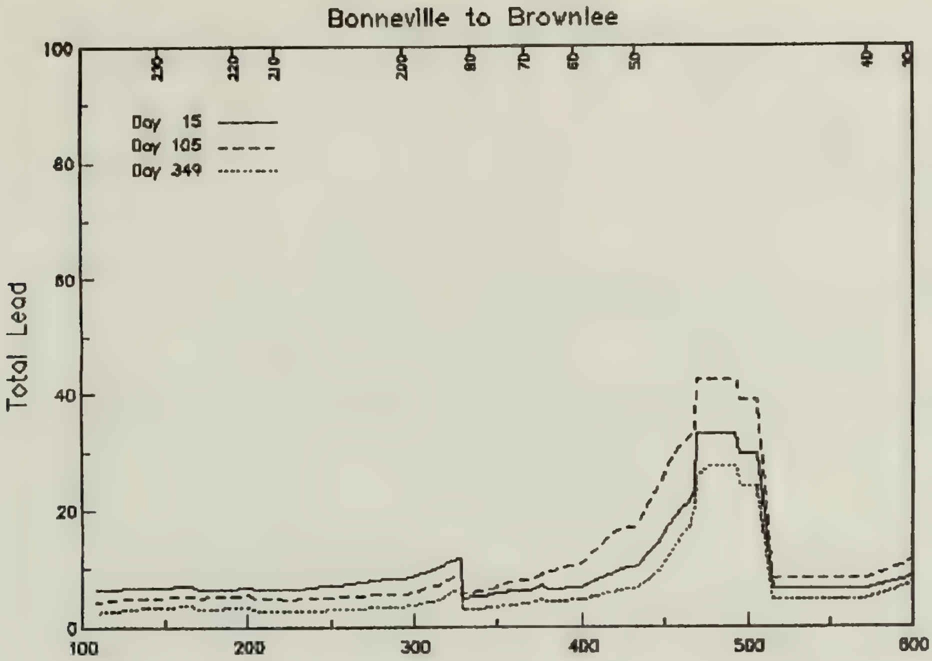


**Figure J–50.** **Total Lead Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 2a**

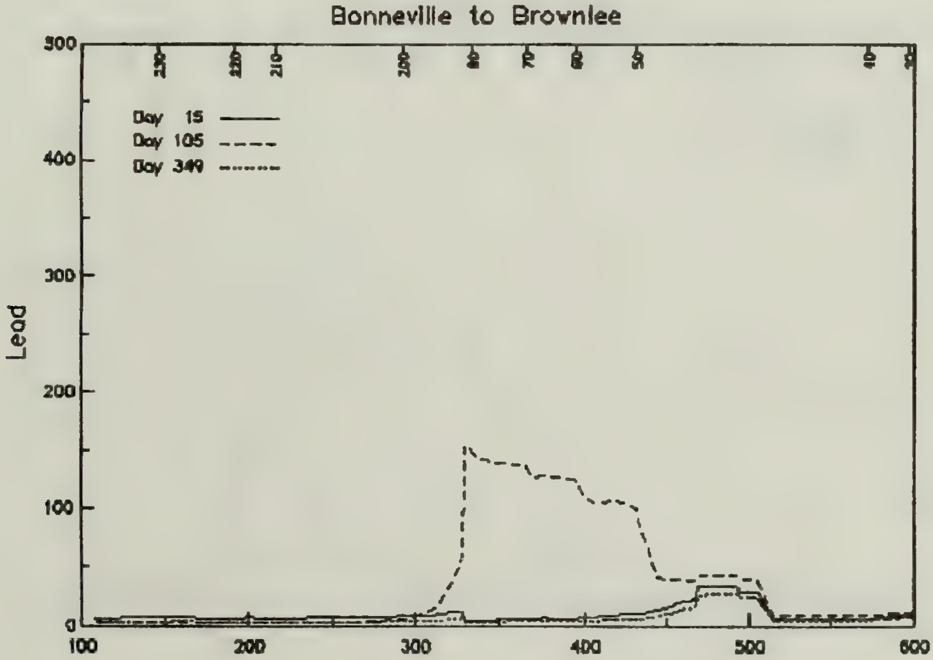


**Figure J–51.** **Total Lead Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 5a**

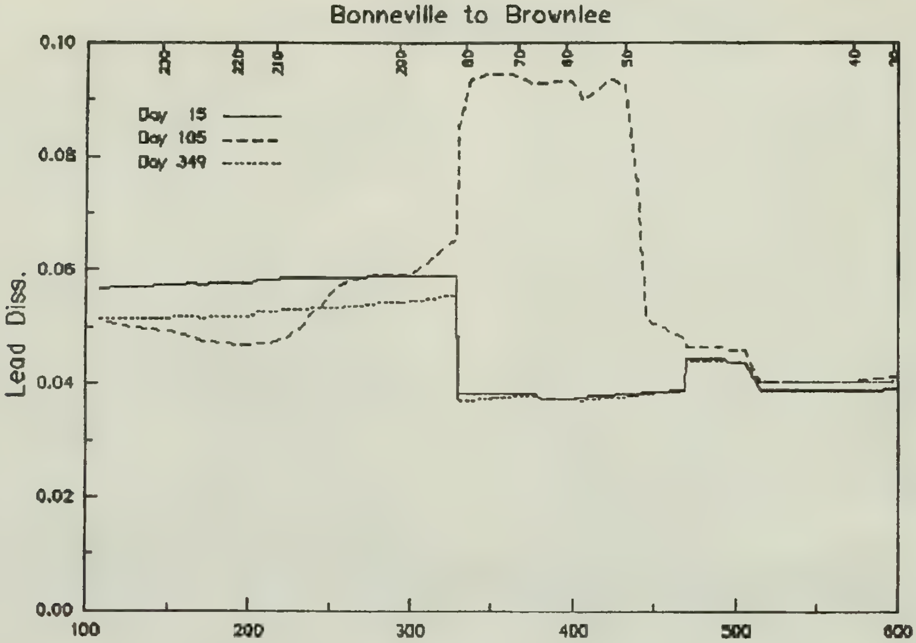


Figure J–52. Dissolved Lead Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 5a

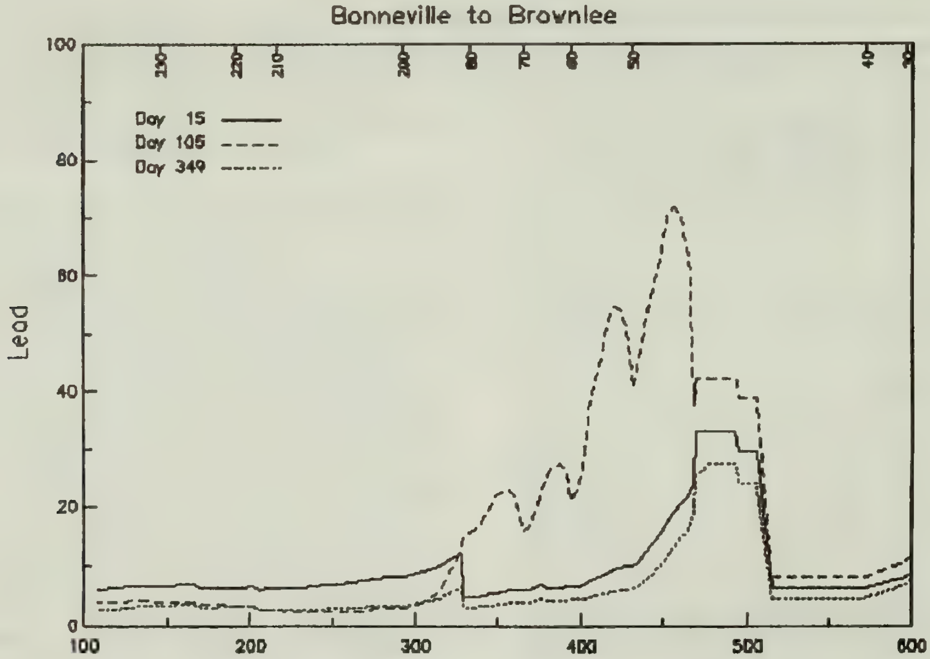


Figure J–53. Total Lead Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 6a

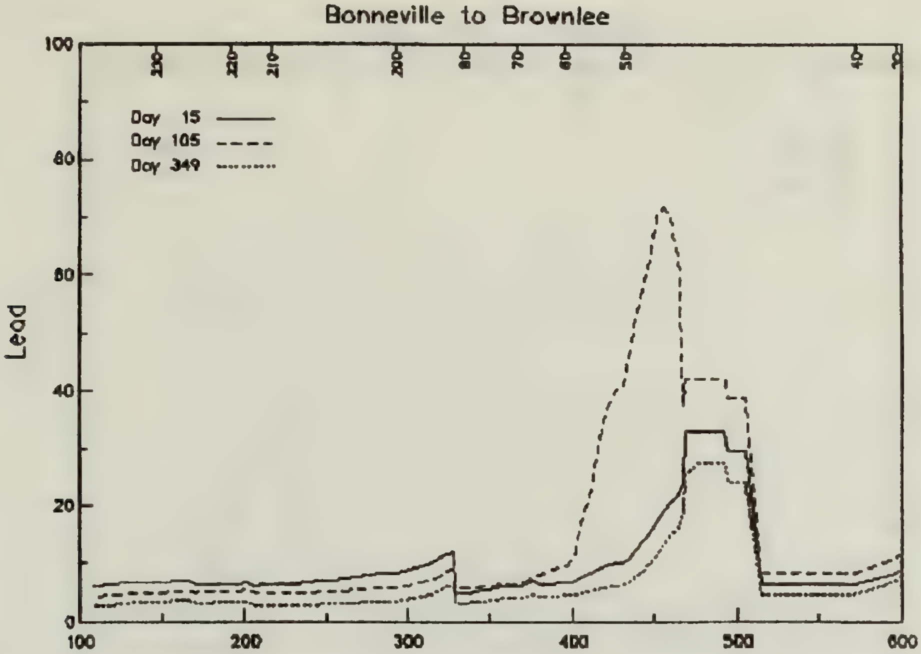


Figure J–54. Total Lead Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 6c

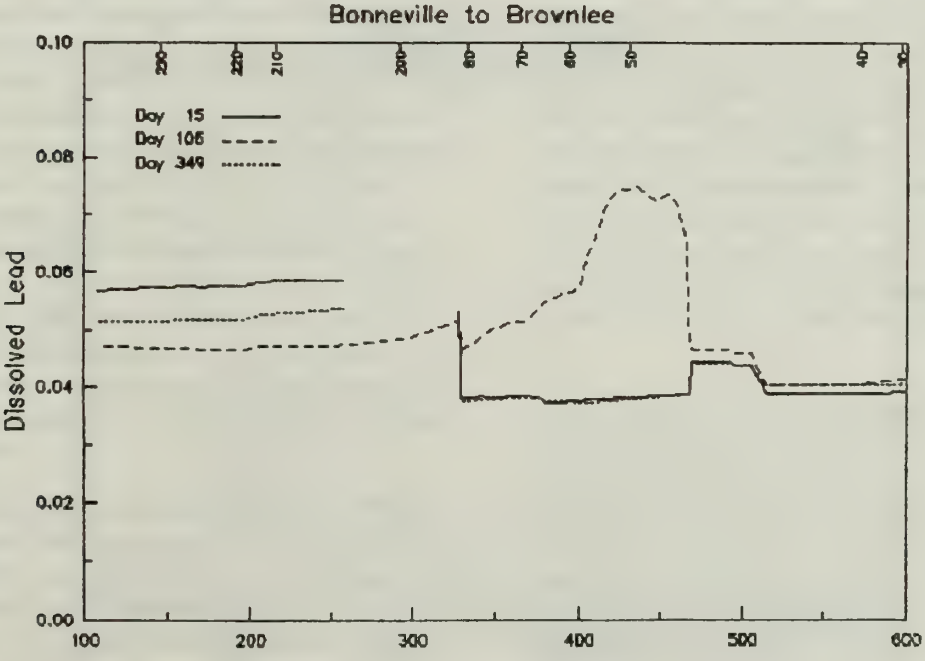


Figure J–55. Dissolved Lead Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 6c

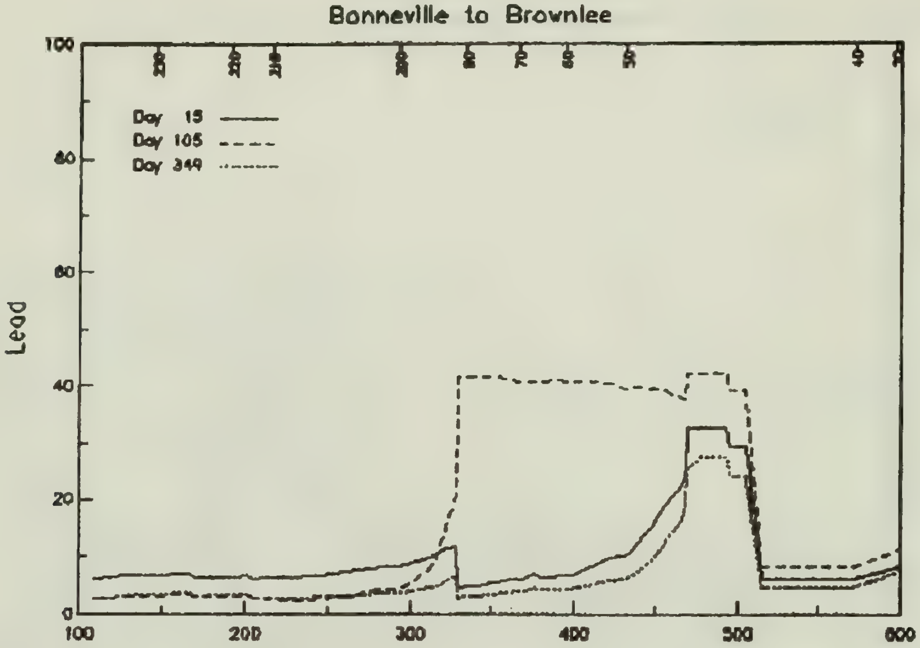


**Figure J–56.** Total Lead Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 2, Alternative SOS 5a

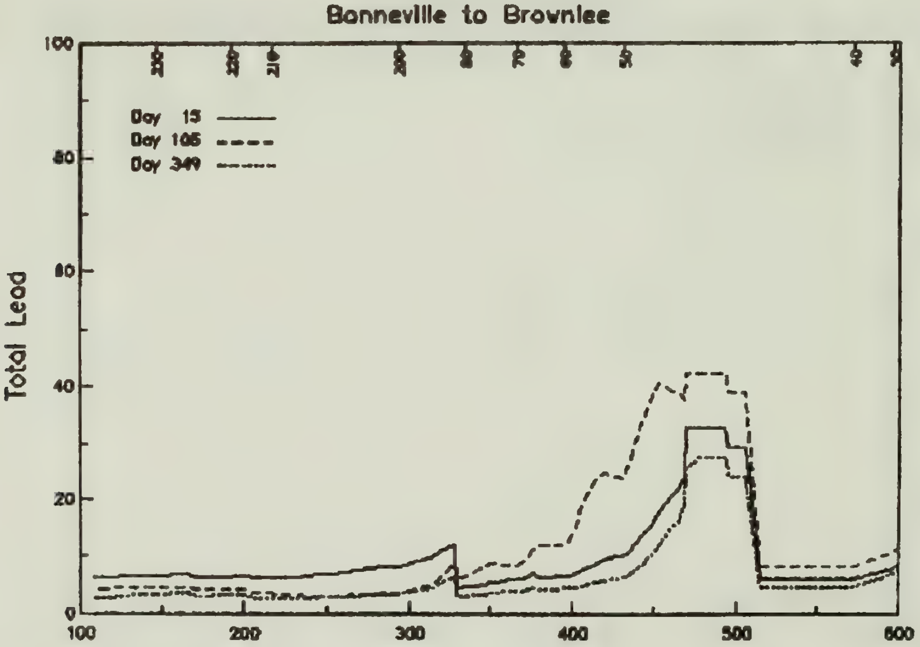


**Figure J–57.** Total Lead Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 2, Alternative SOS 6a

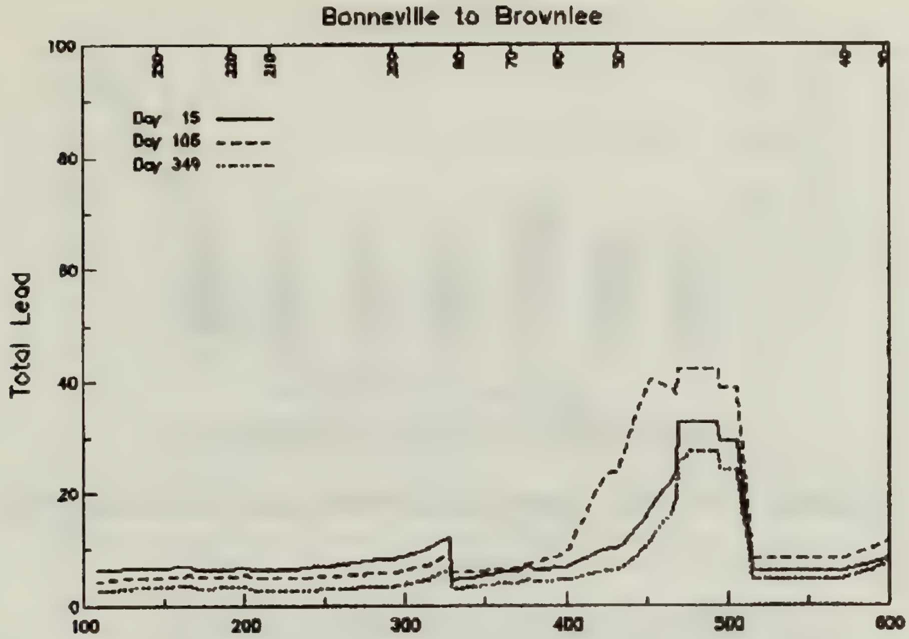


**Figure J–58. Total Lead Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 2, Alternative SOS 6c**

High flows and longer drawdowns should correspond to the greatest total lead exceedences. Exceedence of 15 ug/l total lead during the first two simulated years are greater for the 4½–month drawdowns, as shown in Figures J–59, J–60 and J–61. SOS 5b has the greatest exceedence in simulation year one at high flows. In the second year, the simulation flows were the same for both the high and low–flow conditions (water year 1959 flows). At low flows, total lead exceedence increases after the first year for SOS 6(a–d) at Lower Granite, and for SOS 5b at Ice Harbor. This could be due to the average flows used in the second year of the five–year low–flow condition sequence. The only exceedence of 15 ug/l total lead at John Day occurs during first year high flows.

The five–year average exceedence curves indicate that the water quality standard for total lead (25 ug/l) should be exceeded up to 20 to 30 percent of the time during drawdown operations at Lower Granite and Ice Harbor Dams. Figures J–62 through J–69 show the long–term average exceedence curves. At Lower Granite Dam, simulations show that both SOS 5 and SOS 6 result in these exceedences, as shown in Figures J–62, J–63 and J–64. Only SOS 5 should result in water quality standard exceedence durations greater than 20 percent at Ice Harbor Dam. SOS 6(a,b) exceedence durations are only 10 percent, and SOS(c,d) rarely exceeds the standard at Ice Harbor Dam. Figure J–67 shows an exceedence curve at Priest Rapids Dam for a typical drawdown SOS. This figure indicates that is no significant lead exceedence difference between drawdown and non–drawdown SOSs. At John Day Dam, Figures J–68 and J–69 show that only SOS 5 should result in greater lead exceedences than the non–drawdown SOSs.

Only full drawdown operations on the Snake River should result in an annual lead accumulation in the Columbia River reservoir bed sediments downstream of the confluence of greater than 10 kg/m$^2$. Figures J–70 and J–71 show the lead accumulation profiles for the Columbia River for SOS 5a during the first two simulation years. The accumulation drops during the second year to levels that are about the same as accumulations from mid–Columbia (river mile 400 to 500) tributary loading. Lead, unlike silt, is expected to accumulate as far downstream as John Day Dam.

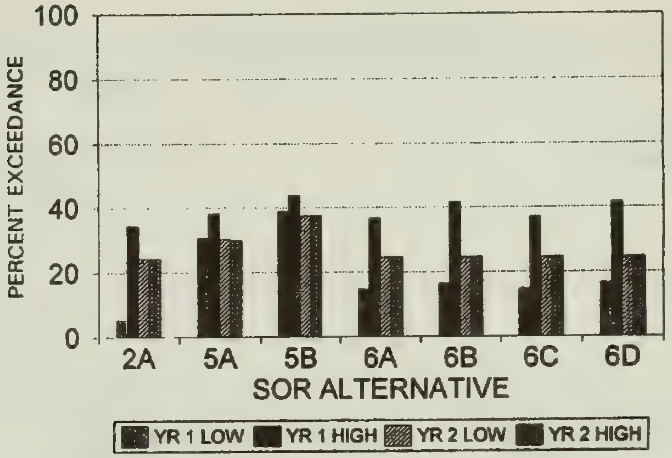


Figure J–59. Exceedence in Year 1 and 2 15 ug/l Total Lead at Lower Granite

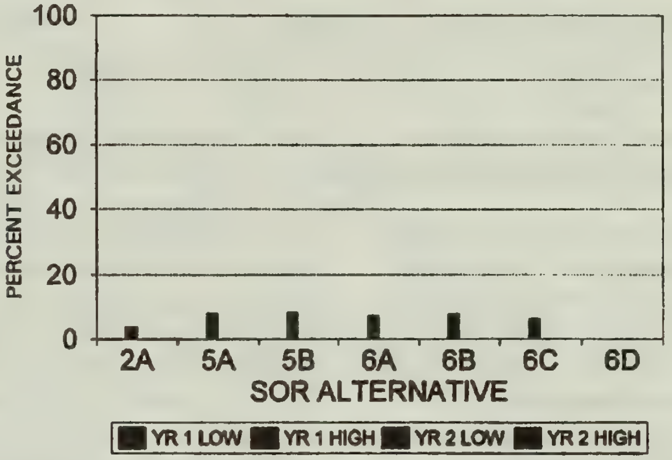


Figure J–60. Exceedence in Year 1 and 2 15 ug/l Total Lead at John Day

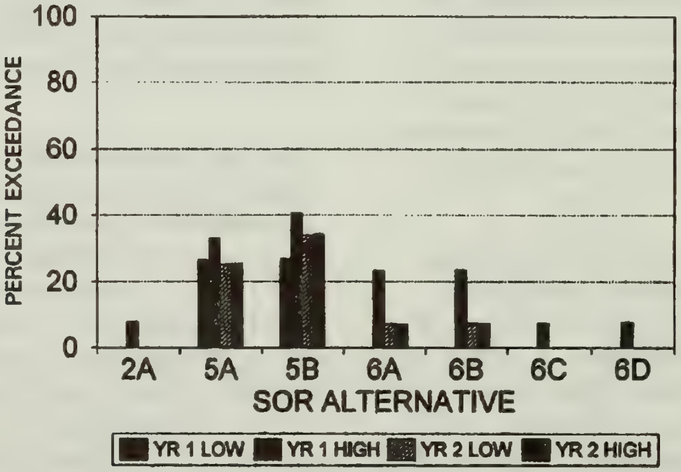


Figure J–61. Exceedence in Year 1 and 2 15 ug/l Total Lead at Ice Harbor

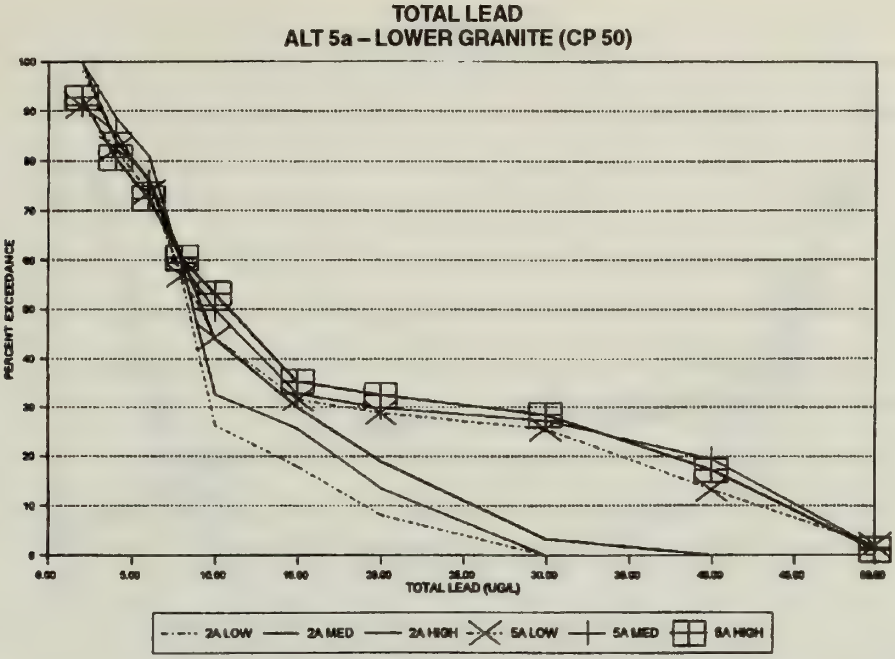


**Figure J–62.** **5–Year Exceedence for Total Lead at Lower Granite Dam for Alternative SOS 5a**

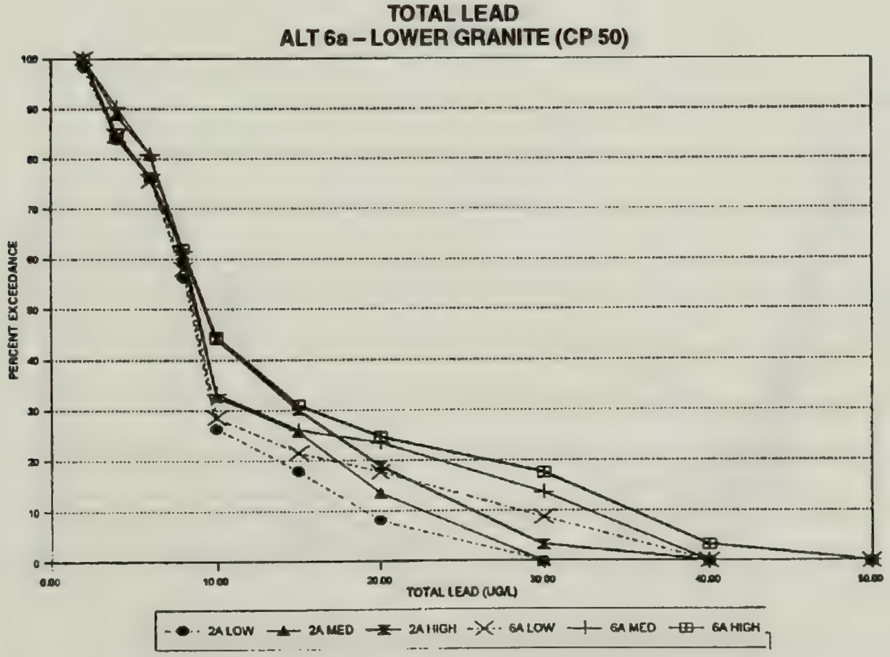


**Figure J–63.** **5–Year Exceedence for Total Lead at Lower Granite Dam for Alternative SOS 6a**

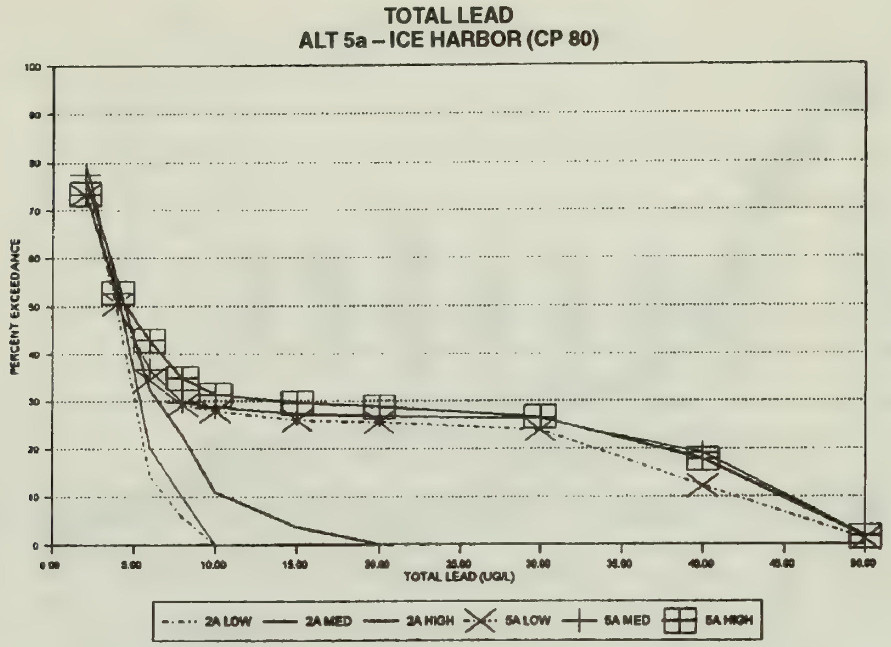


Figure J–64. 5–Year Exceedence for Total Lead at Ice Harbor Dam for Alternative SOS 5a

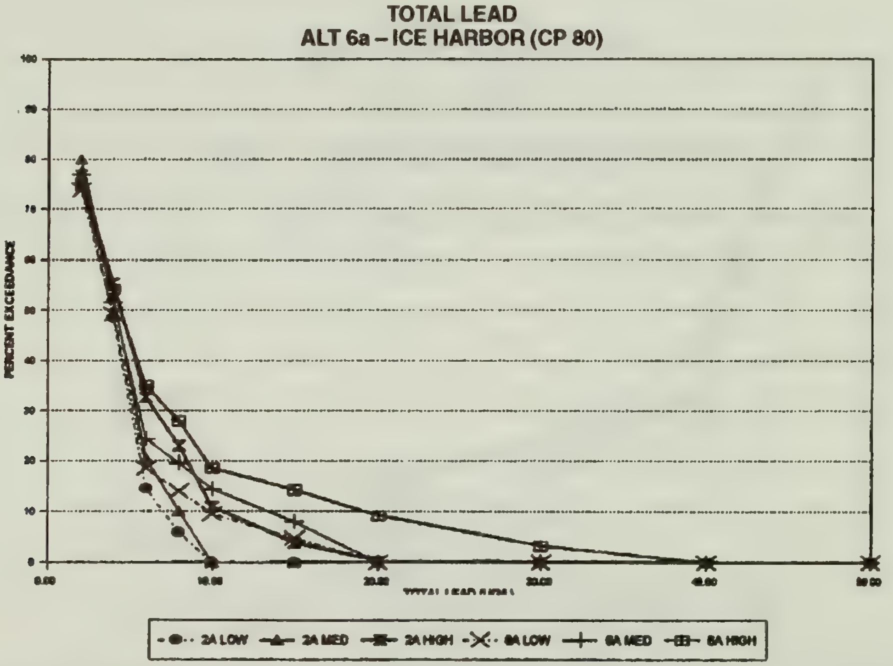


Figure J–65. 5–Year Exceedence for Total Lead at Ice Harbor Dam for Alternative SOS 6a

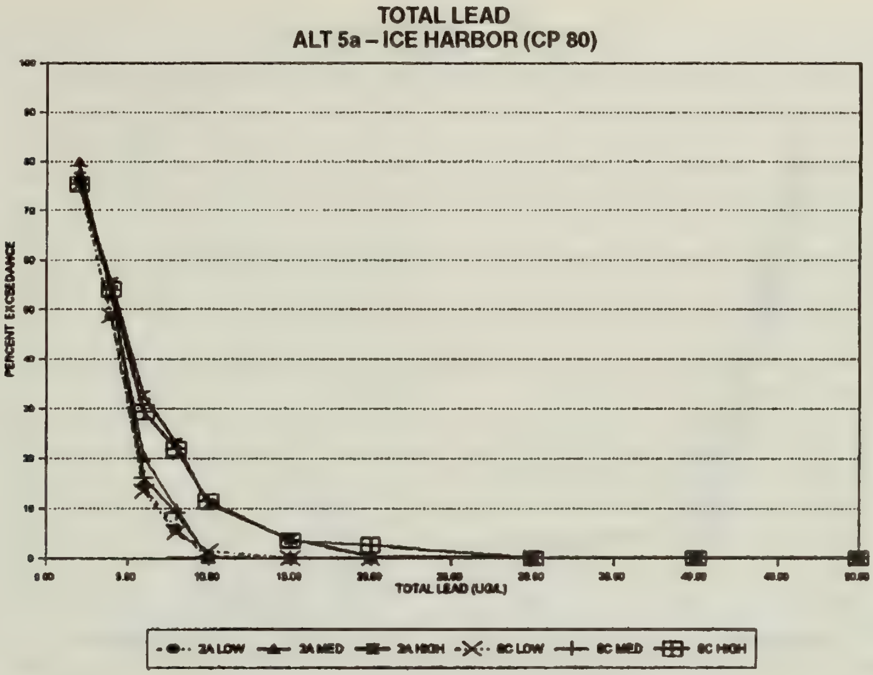


**Figure J–66.** 5–Year Exceedence for Total Lead at Ice Harbor Dam for Alternative SOS 6c

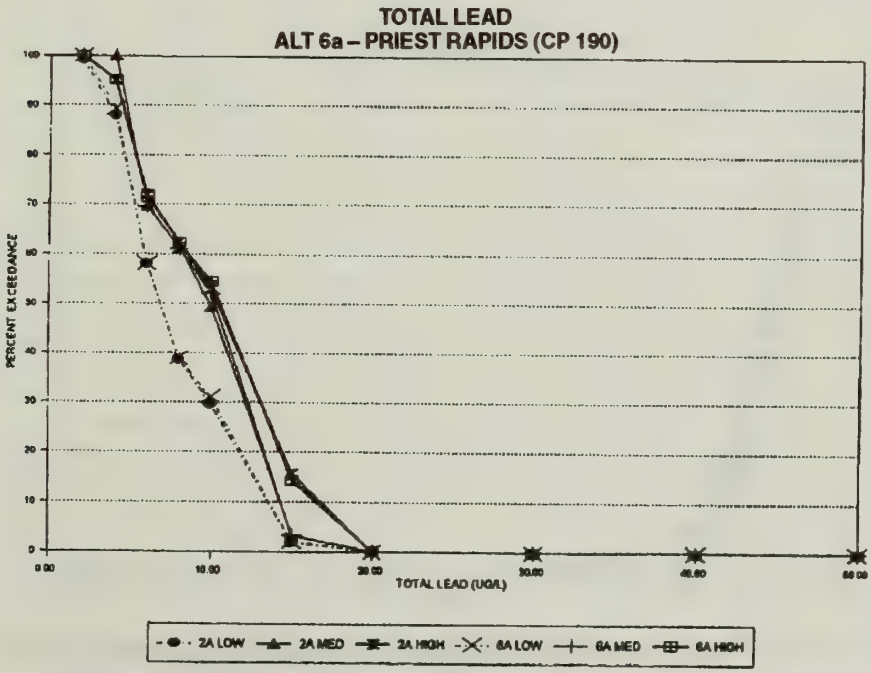


**Figure J–67.** 5–Year Exceedence for Total Lead at Priest Rapids Dam for Alternative SOS 6a

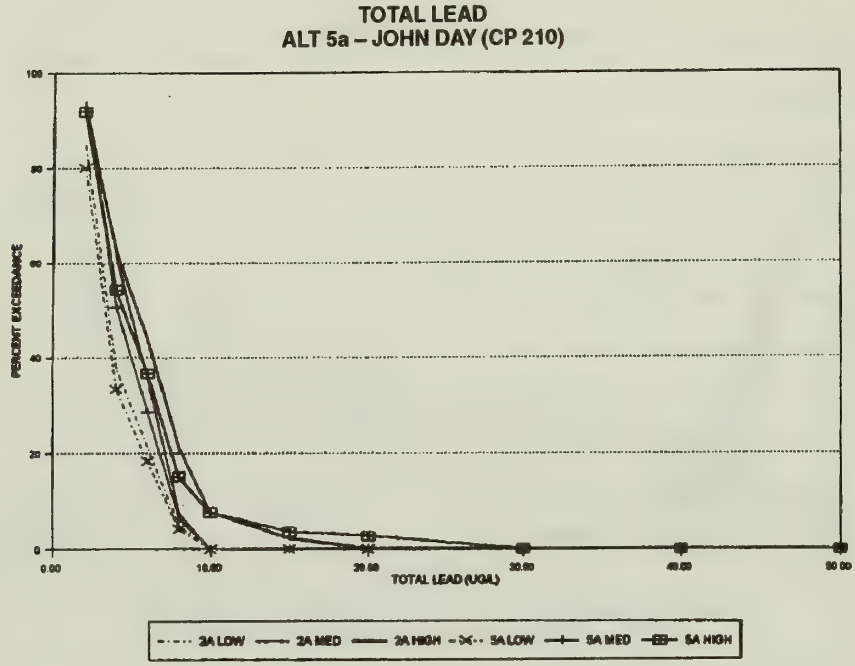


Figure J–68. 5–Year Exceedence for Total Lead at John Day Dam for Alternative SOS 5a

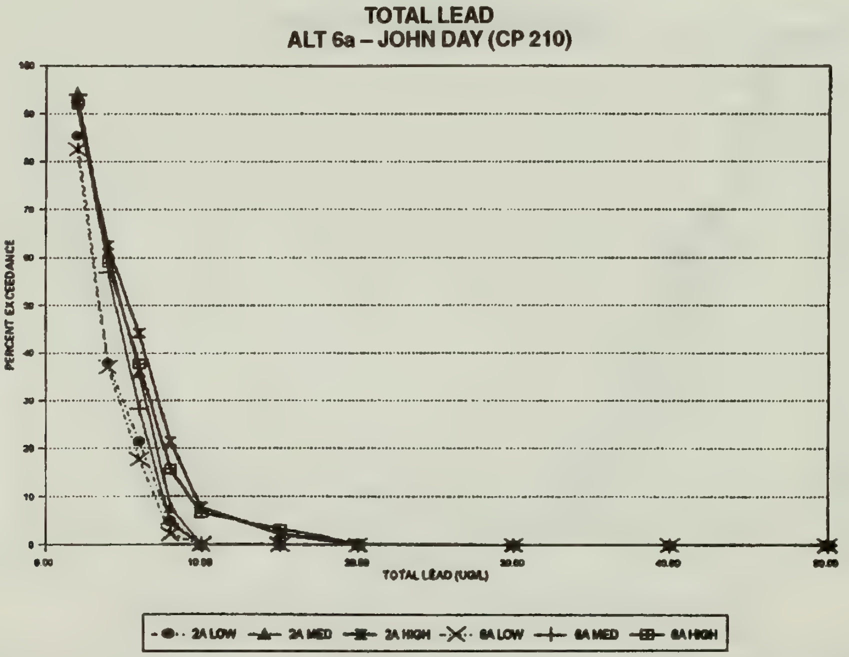


Figure J–69. 5–Year Exceedence for Total Lead at John Day Dam for Alternative SOS 6a

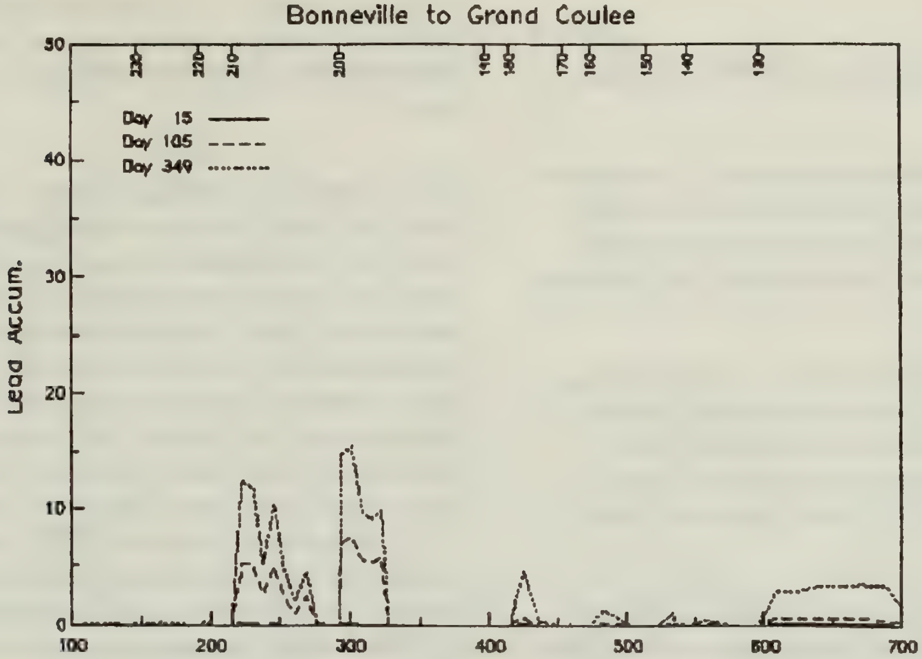


Figure J–70. **Total Lead Concentrations (ug/m$^2$) from Bonneville to Grand Coulee, Average Flow, Year 1, Alternative SOS 5a**

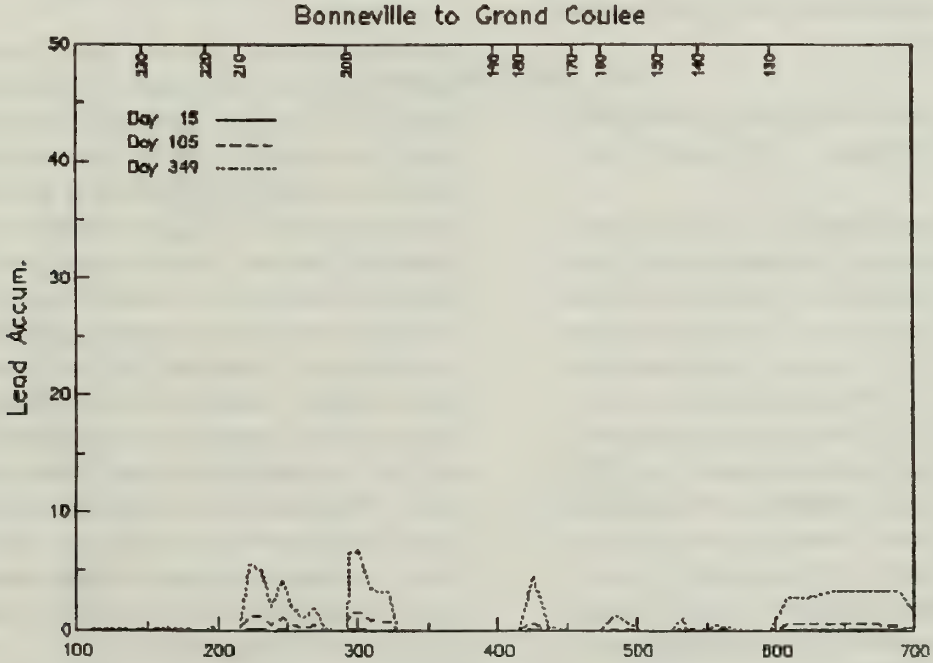


Figure J–71. **Total Lead Concentrations (ug/m$^2$) from Bonneville to Grand Coulee, Average Flow, Year 2, Alternative SOS 5a**

## J–28 TOTAL DDT

The main features of the total DDT simulations are:

- DDT concentration responses to drawdown are similar to those of silt concentrations, because of the presence of DDT sorbed to sediments in lower Snake River reservoir beds.
- DDT simulation results are reported more qualitatively, due to the lack of available DDT data within the Columbia River system causing the simulated DDT concentrations to be based only a few data points.
- With all due consideration of DDT data availability aside, the 0.001 ug/l water quality standard for DDT should be exceeded on an average of up to 5 percent of the time on an annual basis, at Lower Granite and Ice Harbor Dams, during the first five years of SOS 5.

The simulations results demonstrating these main points are plotted in Figures J–70 though J–86.

Simulated DDT distributions are highly sediment transport dependent as in the case of lead. DDT and lead both are hydrophobic which accounts for their dependency on sediment. Figures J–70 and J–71 and Figures J–81 through J–86 show that most of the DDT concentrations are below the current 0.001 ug/l DDT detection limit (which is also the current water quality standard for DDT). Most of the DDT data available for this study was taken from lower Snake River sediment samples, and not from the water column samples. Also DDT concentrations assigned to the mid–Snake River beds and tributaries were estimated based on other river reaches. The results are mainly described in relation to sediments, and how proposed SOR drawdown SOSs could affect DDT distributions.

DDT profiles shown in Figures J–72 through J–78 exhibit the nearly the same peaking patterns as lead. The non–drawdown (base case) profile in Figure J–72 shows that loading from tributaries upstream of Lower Granite Reservoir (river mile 450) increases the concentration in the Snake River. The DDT concentrations slowly decrease downstream as DDT sorbed to sediments settle out in the lower Snake River reservoirs. First–year simulation of drawdowns (Figures J–73 through J–78) show that sediments and DDT scoured from reservoir beds should increase the concentrations threefold throughout the entire lower Snake River for SOS 5. SOS 6 concentrations should at most double within Lower Granite Reservoir, then decrease downstream, but at a slower rate than non–drawdown SOSs.

After the first year, as in the case of lead, upstream maximum concentrations should not be exceeded, as shown in Figures J–67 through J–78. Again, the reduction through the Snake River is slower due to longer free–flowing reaches that do not allow sediments to settle. The flow conditions during the first two years also have the same effect on DDT as they have on lead. Figures J–79 and J–80 show the first and second simulation year exceedences of 0.0004 ug/l DDT at Lower Granite and Ice Harbor Dams. The highest exceedences shown in these figures are for first year high flows with SOS 5b being the greatest among all the SOSs. The exceedence at the high flows drop significantly in year two for SOS 5. At Ice Harbor Dam, the simulations show no exceedences of this concentration in year two for SOS 6, under both high and low–flow conditions.

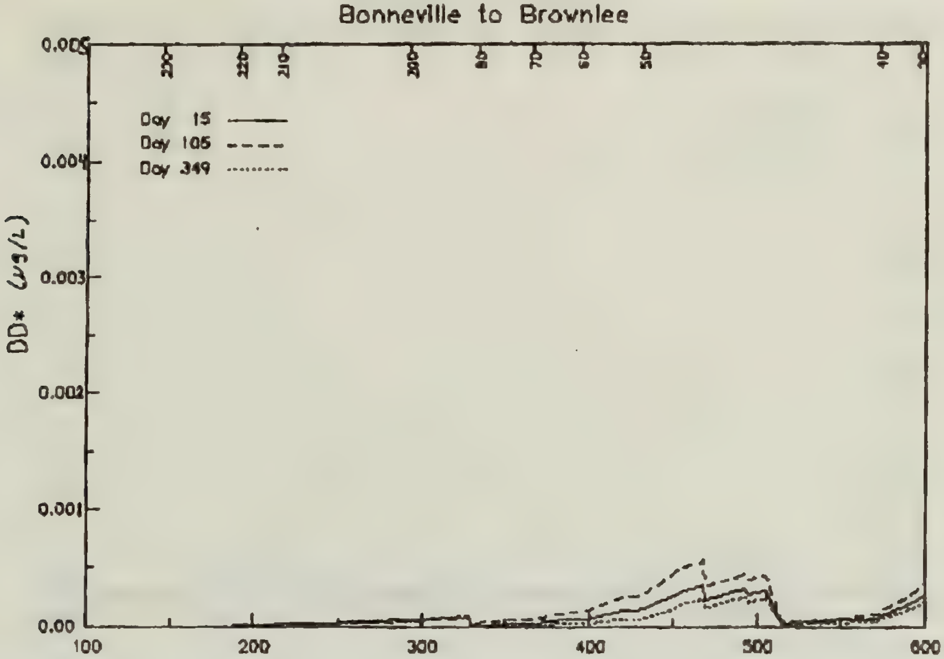


**Figure J–72.** **DDT Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 2a**

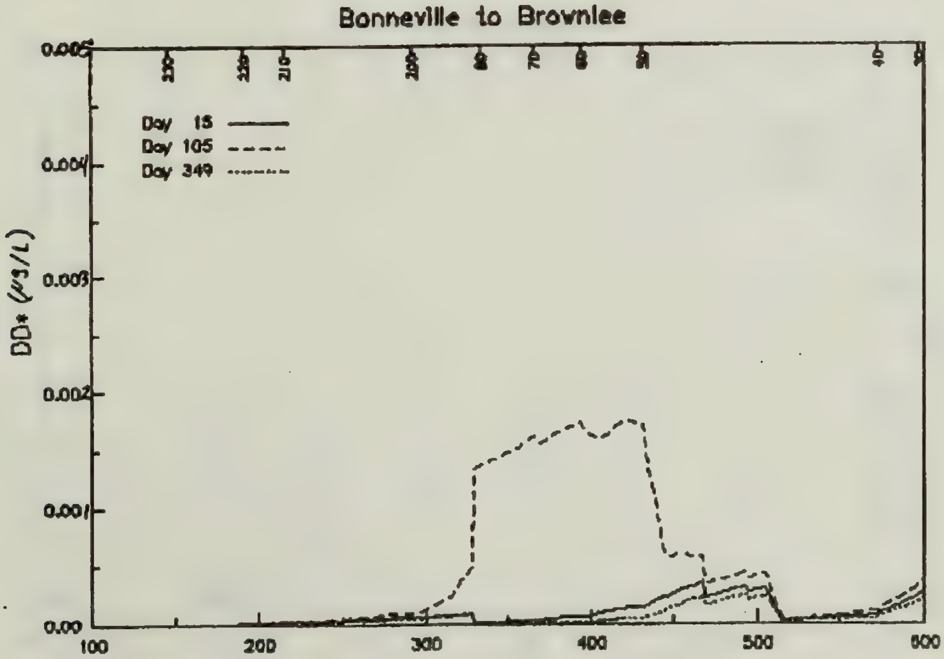


**Figure J–73.** **DDT Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 5a**

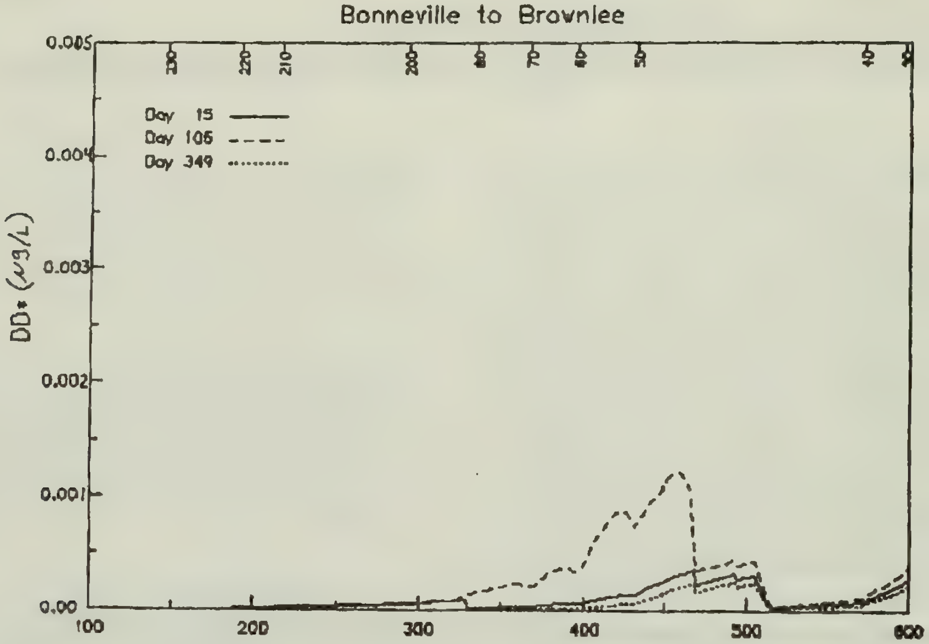


Figure J–74. DDT Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 6a

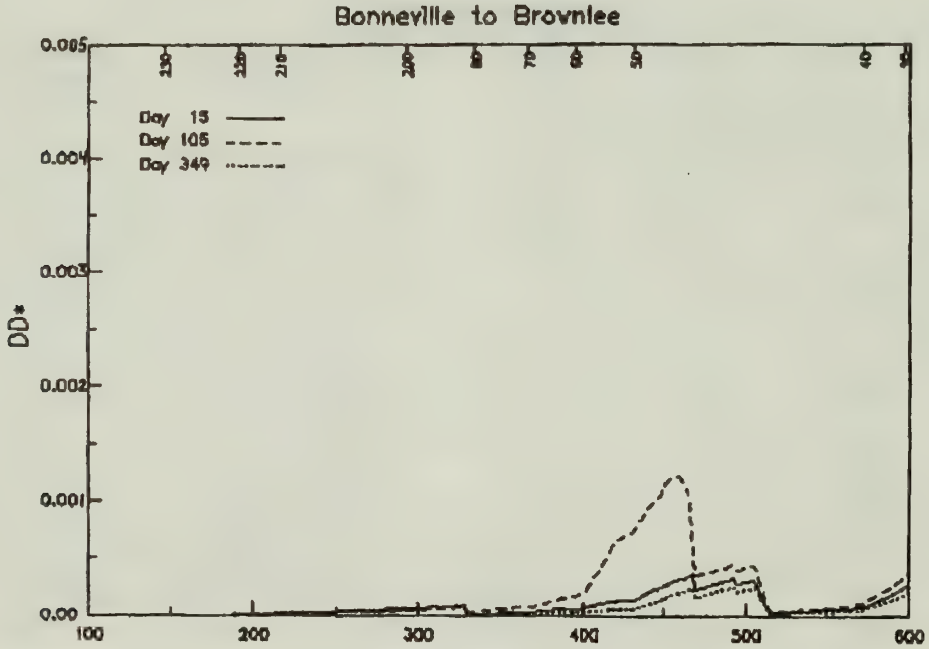


Figure J–75. DDT Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 1, Alternative SOS 6c

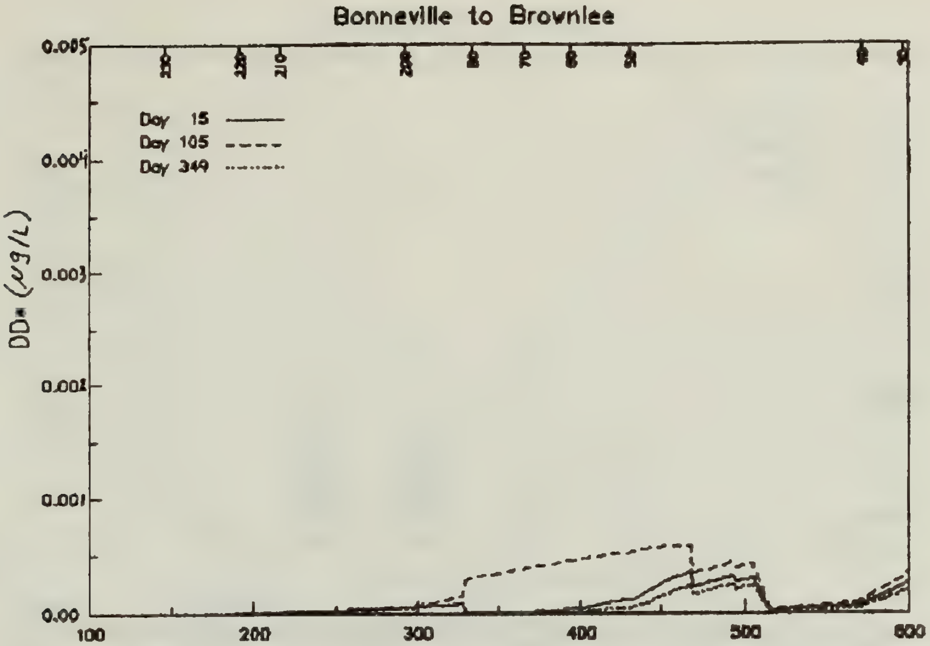


Figure J–76. DDT Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 2, Alternative SOS 5a

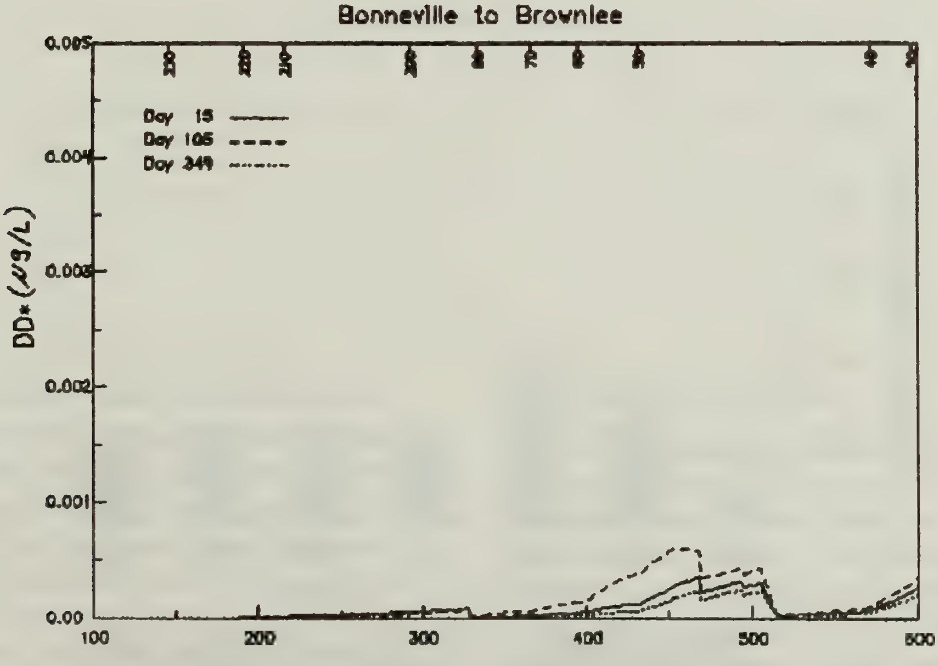


Figure J–77. DDT Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 2, Alternative SOS 6a

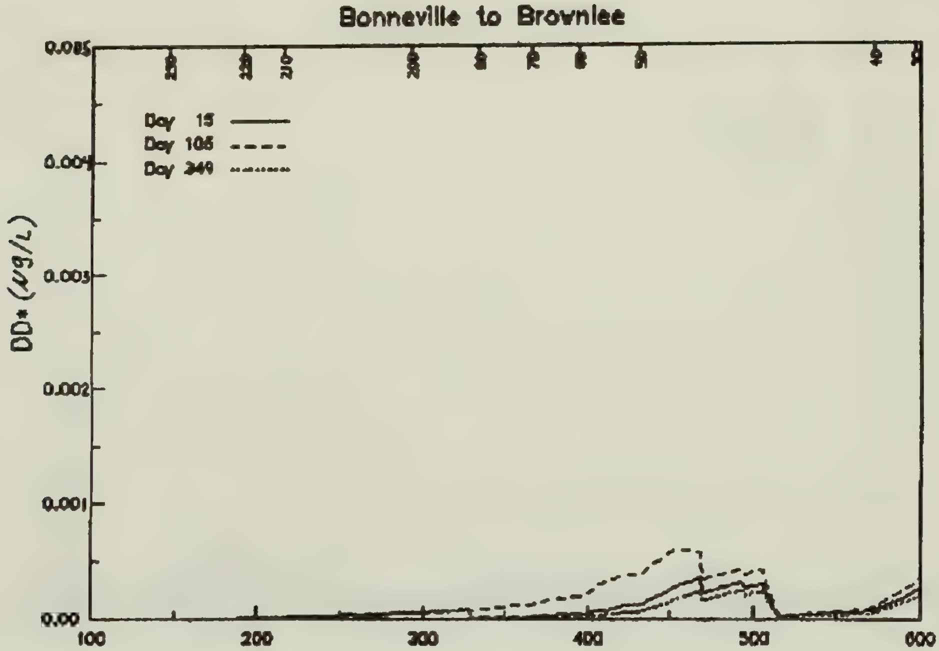


Figure J–78. DDT Concentrations (ug/l) from Bonneville to Brownlee, Average Flow, Year 2, Alternative SOS 6c

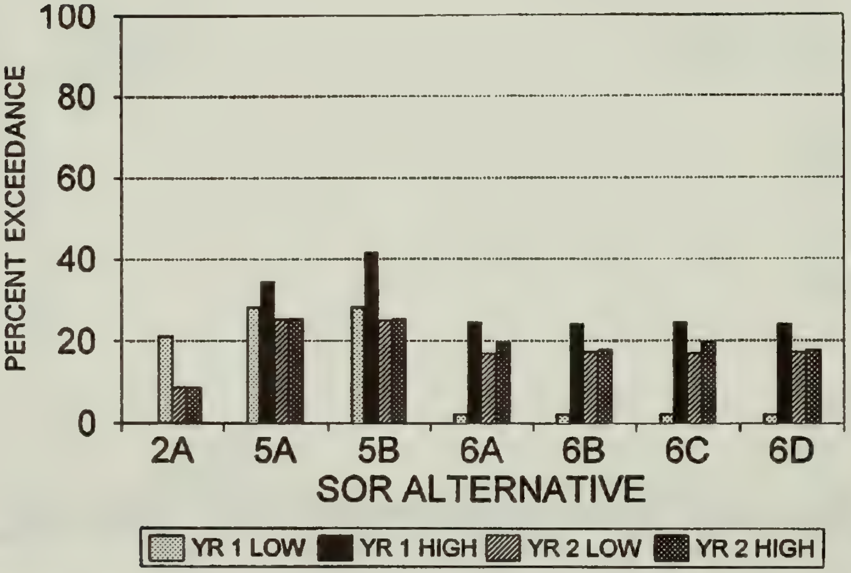


Figure J–79. Exceedance in Year 1 and 2 0.0004 ug/l DDT at Lower Granite

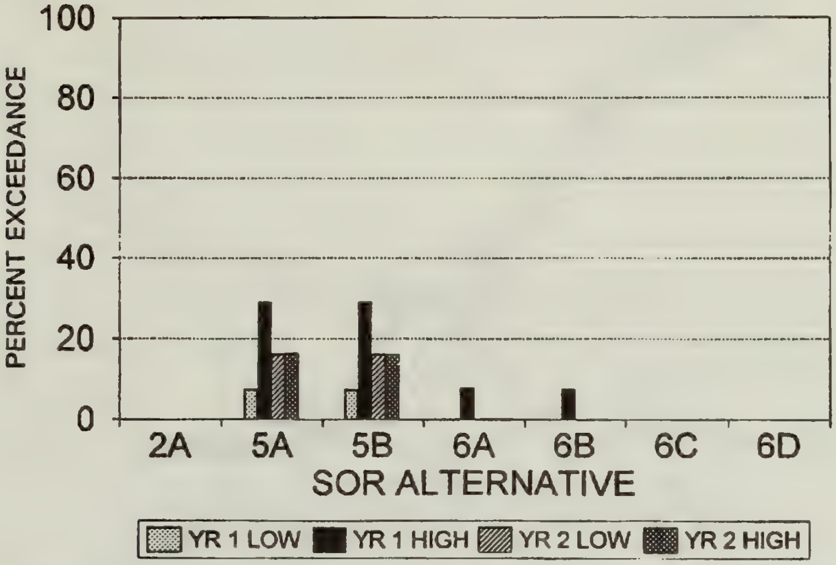


**Figure J–80. Exceedance in Year 1 and 2 0.0004 ug/l DDT at Ice Harbor**

The duration of DDT water quality standard exceedence throughout the five year simulation period was less than five percent at Lower Granite Dam, and near zero at Ice Harbor Dam. Figures J–81 and J–82 show the exceedence curves for Lower Granite Dam. Both SOS 5 and SOS 6 curves indicate exceedence of the 0.001 ug/l DDT standard. Non–drawdown curves do not show exceedence of this standard. Figures J–83 through J–85 show the exceedence curves for Ice Harbor Dam. Only the SOS 5 curve indicates an exceedence of 0.001 ug/l DDT, albeit a very small one.

The greatest departure from non–drawdown SOSs is shown in Figure J–83 for SOS 5. This indicates that during full drawdown sediments and DDT from upstream tributaries and reservoir beds should be transported past Ice Harbor Dam, and most likely is deposited in Lake Wallula on the Columbia River. Figure J–86 shows that SOS 5a exceedence is slightly higher SOS 2a, but only at extremely low concentrations. DDT accumulation in Lake Umatilla should be very small.

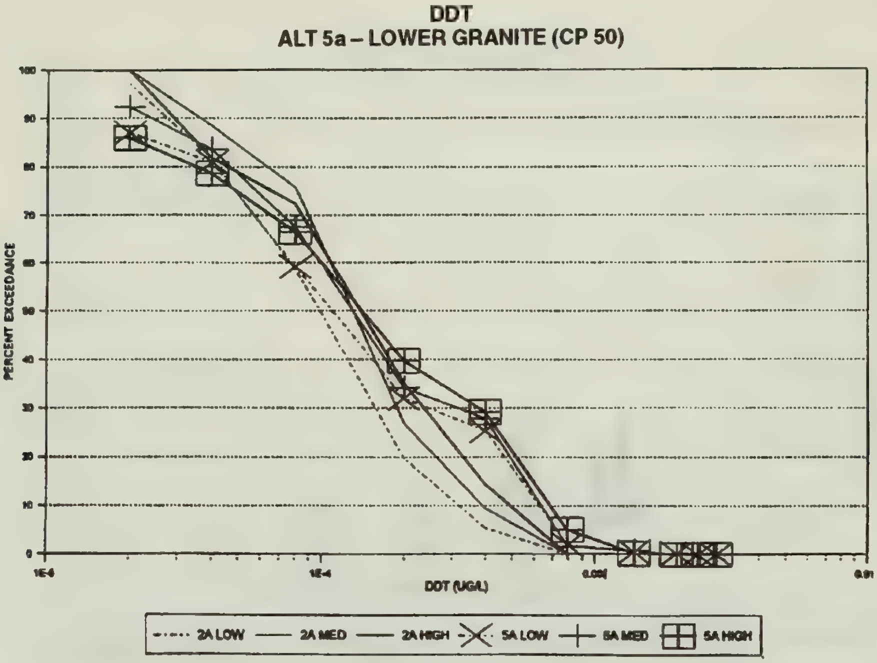


Figure J–81. 5–Year Exceedence for DDT at Lower Granite Dam for Alternative SOS 5a

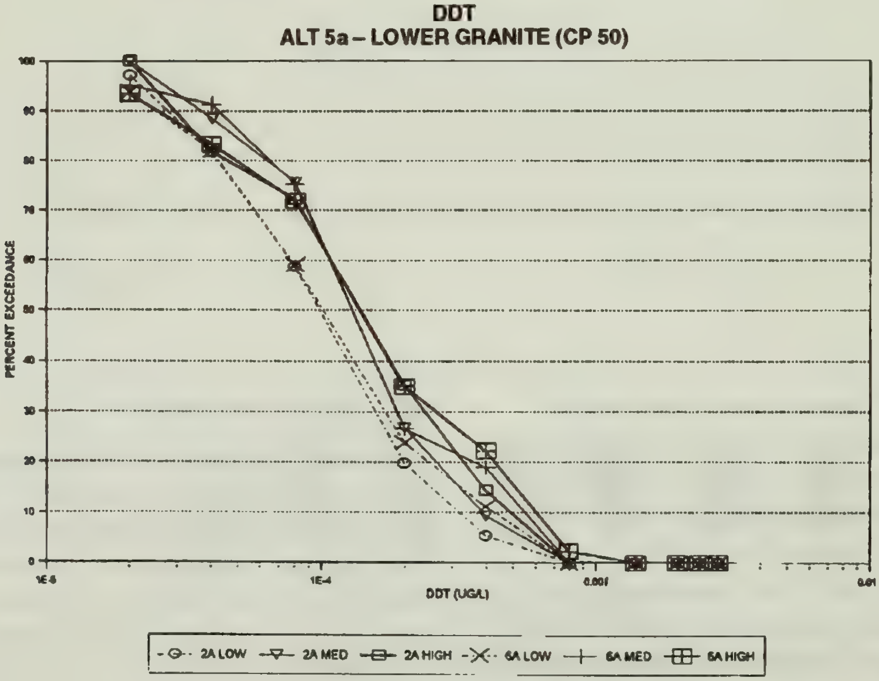


Figure J–82. 5–Year Exceedence for DDT at Lower Granite Dam for Alternative SOS 6a

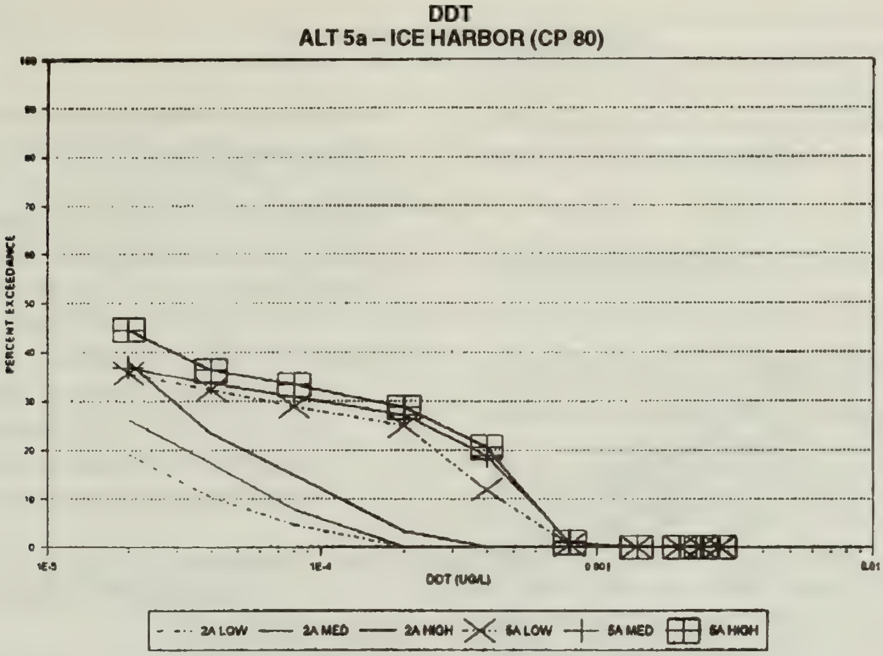


Figure J–83. 5–Year Exceedence for DDT at Ice Harbor Dam for Alternative SOS 5a

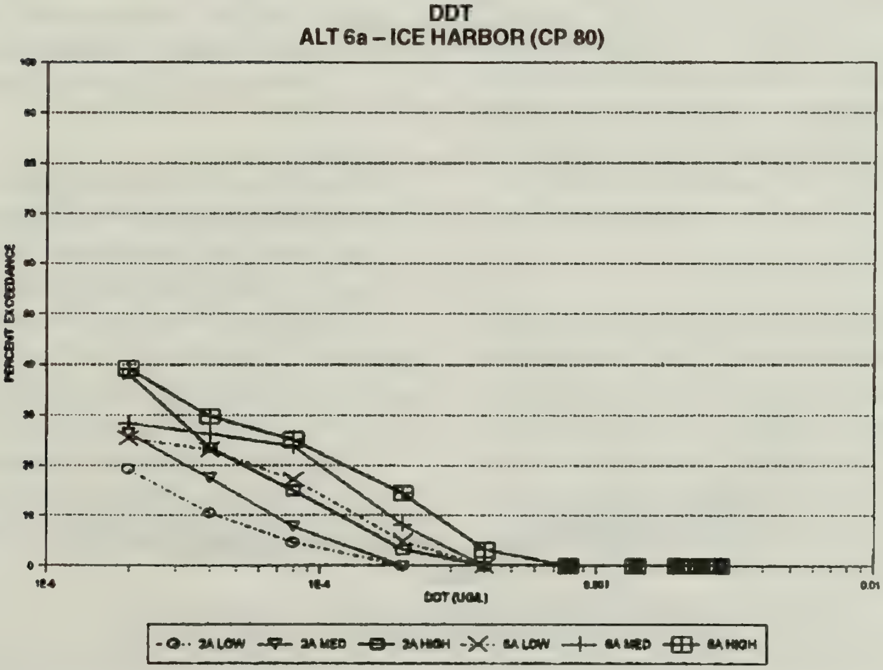


Figure J–84. 5–Year Exceedence for DDT at Ice Harbor Dam for Alternative SOS 6a

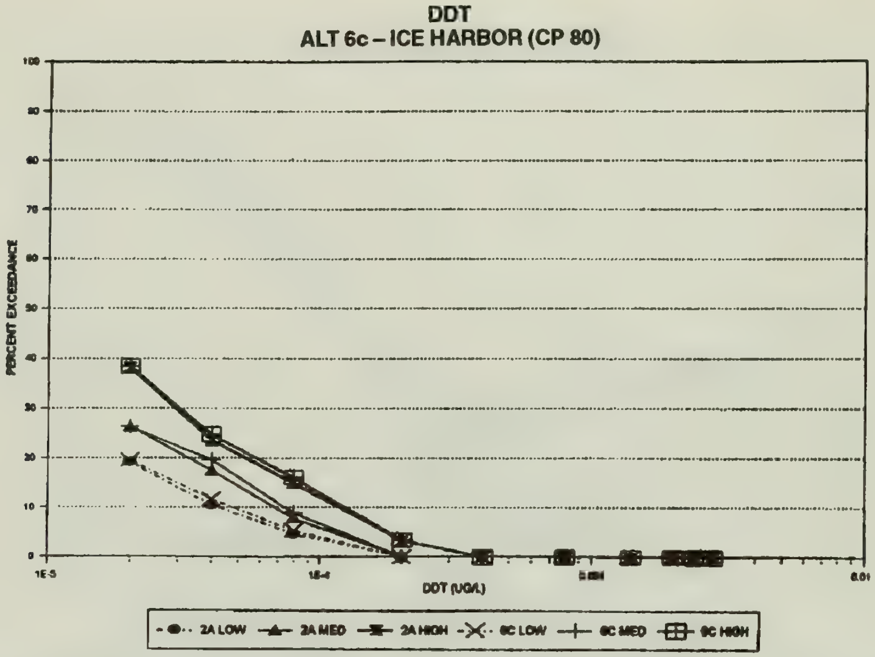


Figure J–85. 5–Year Exceedence for DDT at Ice Harbor Dam for Alternative SOS 6c

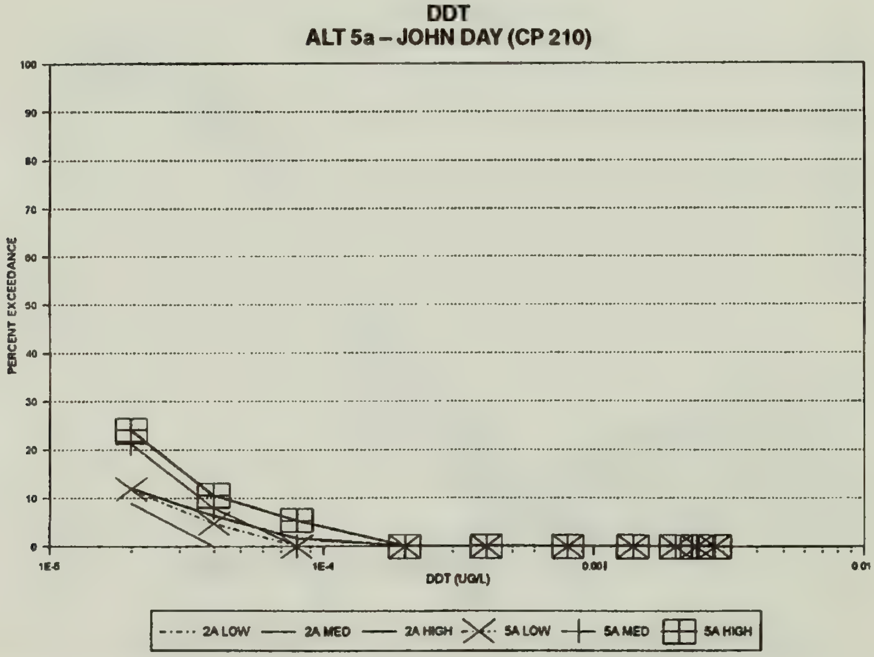


Figure J–86. 5–Year Exceedence for DDT at John Day Dam for Alternative SOS 5a

## J–29 DISCUSSION

The full–scale water quality model simulated the transport of lead, total DDT, and ammonia in the mainstem Columbia and lower Snake Rivers. As in the analysis of sediment transport results, these parameters concentrations were compared using exceedence thresholds that were selected to determine differences between the SOR drawdown and non–drawdown alternatives. The exceedences are shown in Figure J–87 through J–90. The results shown in these tables indicate that only DDT and lead exceedences vary significantly between the base case and drawdown SOSs.

## J–30 EXCEEDENCE THRESHOLDS

The lead, DDT, and ammonia thresholds were chosen to show differences between SOSs. Like the thresholds selected for water temperature and sediment transport, these also do not necessarily coincide with water quality standards. The exceedence threshold is 15 ug/l for lead, 0.0004 ug/l for DDT, and 0.1 mg/l for ammonia. They are water column total concentrations. All the chosen thresholds are below water quality standards.

The standards for lead and ammonia are dependent on other factors that vary within the system, and over time. The EPA standard for lead (based an average hardness in the Columbia River of 57 mg/l) is 25 ug/l, and for ammonia (based on an average water temperature of 59 of (15 oC), and a Ph of 8.0) is 0.75 mg/l $NH_3$+$NH_4$. The model results show no exceedence of the ammonia standard, and minor variation between the computed exceedences of the base case and drawdown SOSs, so details of ammonia exceedences will not be discussed.

The standard for DDT is 0.001 ug/l. The DDT threshold is actually below current detection limits. The DDT water column total concentrations being computed by the model are most likely coming from desorption of pollutants that have accumulated in the Snake River bottom sediments, after they get scoured into the water column during drawdown operations.

## J–31 LEAD AND DDT

The model results for lead and DDT show the similar trends found for silt. Alternative 5b should generate the greatest lead and DDT exceedences of all the SOSs. Again, no significant departure from the base case is expected at the Columbia River locations Priest Rapids and John Day Dams. The reduction in exceedence between alternatives 5b and 6a/b, and between Lower Granite and Ice Harbor Dams is also similar to that for silt.

The exceedence difference between the base case and the other drawdown SOSs at Lower Granite Dam is better shown by exceedence curves. At an exceedence threshold of 25 ug/l lead, the model shows an exceedence increase of about 25 percent for alternative 5b over the base case. This is closer to the silt trends expected at Lower Granite Dam. Figures J–87 through J–90 shos alternative 2a and 5b lead and DDT exceedence duration curves generated from model simulations at Lower Granite and Ice Harbor Dams.

The trends in the computed exceedences indicate that lead and DDT accumulated in the Snake River sediments would be transported downstream with the sediments during drawdown operations. For the natural river drawdowns, lead and DDT would deposit in Columbia River just downstream of the confluence with the Snake River. For the SOS 6 alternatives, the lead and DDT would deposit in the partially drawn down pools. The process of desorption of the contaminants from sediment particles may produce a sediment cleansing effect, but it may also cause water quality standard exceedences in the water column.

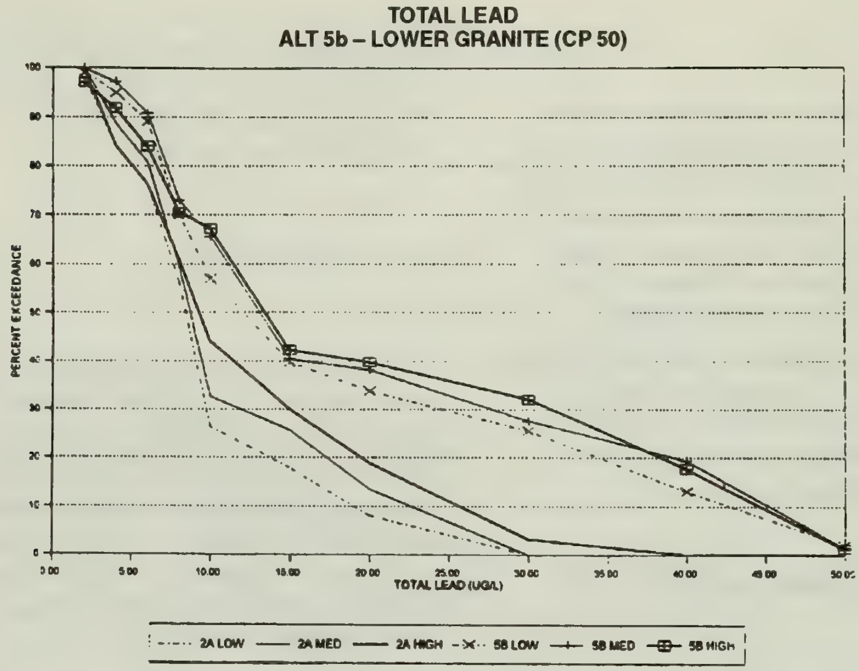


**Figure J–87.** 5–Year Exceedence for Total Lead at Lower Granite Dam for Alternative SOS 5b

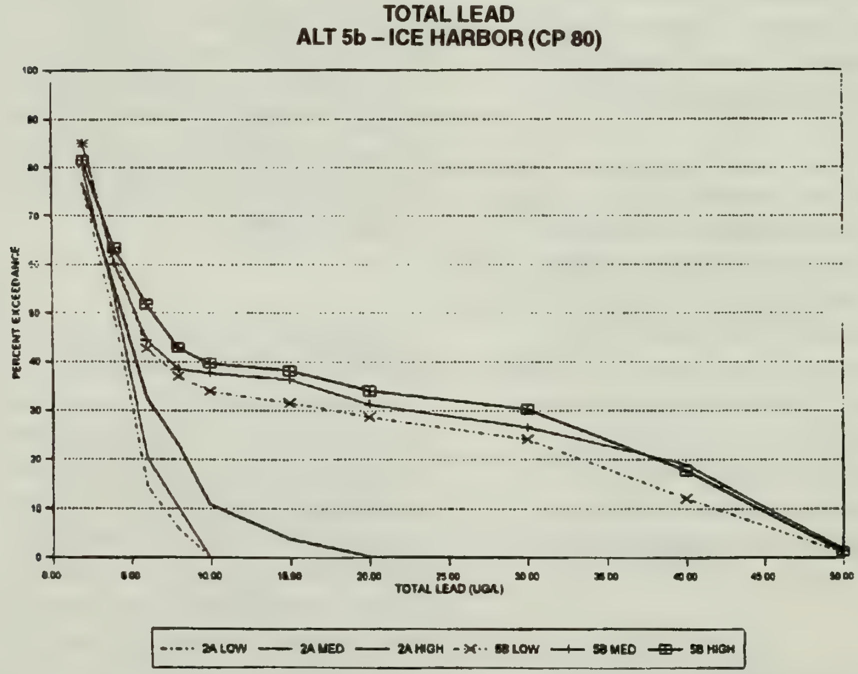


**Figure J–88.** 5–Year Exceedence for Total Lead at Ice Harbor Dam for Alternative SOS 5b

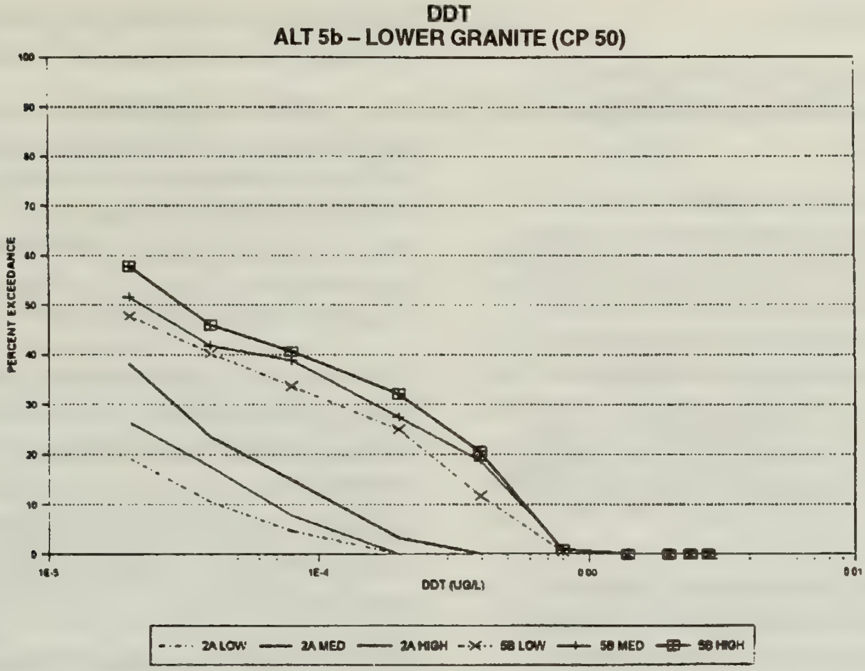


Figure J–89. 5–Year Exceedence for DDT at Lower Granite Dam for Alternative SOS 5b

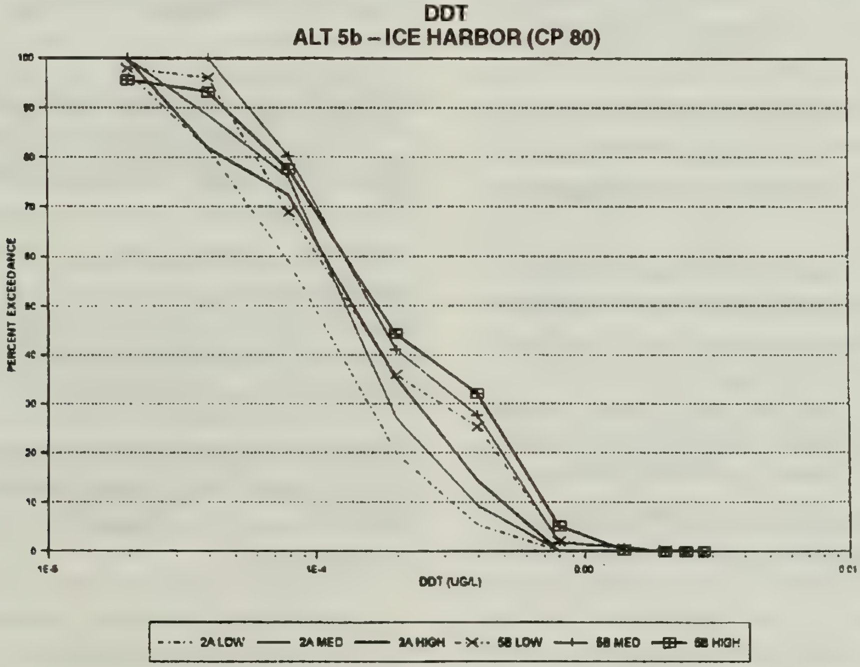


Figure J–90. 5–Year Exceedence for DDT at Ice Harbor Dam for Alternative SOS 5b

## J–32 LITERATURE CITED

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## ATTACHMENT J1

## SHORELINE EROSION MODEL METHODOLOGY

### J1–1 INTRODUCTION

During the 1992 Lower Granite drawdown test, turbidity significantly increased and damage to structures occurred as a direct result of erosion and mass–wasting. In order to understand the types and degrees of impacts that alternatives with drawdowns would have, it was decided to semi–quantitatively account for the impacts of shoreline erosion for the proposed drawdown alternative. The model developed for shoreline erosion is one of the first attempts to quantify erosion resulting from drawdown. The results of the model will be used in the HEC–6 modeling of instream erosion and sedimentation and also in the HEC–5Q modeling of water quality. The shoreline erosion model considers only Lower Granite reservoir, since it is the best documented on the lower Snake. Erosion of the shorelines on other Snake River reservoirs will be extrapolated from the model's results. Impacts of alternatives to other reservoirs in the Columbia River basin other similar in nature and extent to previously proposed operations (Corps, 1993).

Four erosion processes were identified as being significant for the reservoir: tributary incision, slumping of shoreline materials, wave erosion of the banks, and surface erosion of sediments exposed to rainfall. Due to the lack of storm activity during March of 1992, very little surface erosion took place, and wave erosion was minimal.

This study estimates, using the best available data, the amount of sediment that would be generated from the exposed shorelines on Lower Granite Reservoir under the drawdown alternatives. The range of sediments considered was from fine gravel to clay. The nine drawdown alternatives differ in length of time (2 months versus 4.5 months) and in amount of drawdown (113, 28, and 58). To give an idea of the possible range erosion, three scenarios were chosen to calculate low erosion, moderate erosion, and high erosion.

For each of the four erosional processes, a spreadsheet was derived showing the estimated erosion for each of the alternatives and each scenario. The total erosion is shown in a separate spreadsheet which sums the nine segments of the reservoir used in calculations to 3 input areas to be used in the HEC–6 model. The input areas refer to segments of the reservoir; segment 1 is between RM 107.3 and 120; segment 2 is between RM 120 and 135; segment 3 is between RM 135 and 146 and includes the Clearwater River to RM 5.8. Given the amount of error possible in the HEC–6 modeling, further subdivision of the reservoir is not necessary. If, however, further refinement in the model calls for a more detailed breakdown of input areas, it will be relatively easy to go back in the spreadsheets and retrieve the appropriate estimates.

The areas used for the model were derived from several sources. Armored areas (those areas not susceptible to the above types of erosion) were identified using aerial photographs. The pre– and post–reservoir shorelines were derived from 1:24,000 scale U.S.G.S. topographic maps. These were also used to map the armored areas. The minimum operating pool elevation (MOP) and the pre–reservoir river shoreline were used to established polygons within the GIS to apply the various calculations. MOP was used as the upper boundary of the polygons since the normal operating of the reservoir has removed much of the sediment above 733 feet. Erosion of these areas during the drawdown is assumed to be negligible. The 705 foot pool elevation was derived from a bathymetric grid as was entered into the GIS to define polygons for the two fixed drawdown alternatives. The grid coverage of the confluence area was poor, so the 705 pool shoreline was interpolated using the 733 shoreline and the

697 (from the 1992 drawdown test) shoreline. Although there is some deviation between the interpolated shoreline and the actual shoreline in the upper reservoir, due to change in water surface slope, the area exposed is probably only slightly underestimated, since 697 shoreline was the actual shoreline during the drawdown.

The areas exposed by the natural river drawdown and the fixed drawdown were used to interpolate the amount of erosion that would occur during the intermediate drawdown alternatives (7a &7b). The relation was then used to derive the areas for alternatives 7a and 7b. To calculate the total erosion under alternatives 7a and 7b, the ratio of the area exposed under alternatives 6a and 6b to the area exposed under alternative 7a and 7b was multiplied by the total sediment eroded in tons under alternatives 6a and 6b. This turned out to be only 7% higher than for alternatives 6a and 6b, indicating that much of the area to be exposed during a drawdown is exposed during the first 10 to 20 feet of drawdown.

## J1–2 SURFACE EROSION

As the reservoir shoreline drops, an increasing amount of shoreline is exposed. This surface is composed primarily of fine sediments, especially toward the dam. Without any vegetation or soil structure, the sediments are highly erodible, by both wind and water.

A common way of estimating the amount of sediment eroded from slopes is the Universal Soil Loss Equation. (Wischmeier and Smith, 1978).

$$X = R*K*LS*C*P$$

Where: X = the computed soil loss in tons per acre from a given storm period

R = rainfall erosion index for the given storm period

K = soil erodibility factor

LS = slope length factor

C = cropping management (vegetation) factor

P = erosion control practice factor

The rainfall erosion index was derived using the equation for Type II storms:

$$R = 27*(P2.2)$$

Where: P = the amount of rainfall in inches for a given storm type

The 2–year, 5–year, and 10–year, 6–hour rainfall amounts (Miller et al., 1973) were used to calculate low, moderate, and extreme conditions. The annual rainfall index needed to be adjusted to the duration of the drawdown. This was done by multiplying by the index by the percent of annual rainfall normally occurring during the months of drawdown. For the April–June alternatives, the factor was 0.31. For the April–August, the factor was 0.41.

The soil erodibility factor (K) was estimated using the nomograph developed by Wischmeier and Smith (1978). The nomograph uses soil texture, structure and permeability. The soil texture was derived for each reservoir segment using the average of sediment sample distributions (Corps, 1982, 1988, 1989, 1992). The structure was assumed to be fine granular for lake sediments, and the permeability (rapid to very slow) was estimated based on soil texture. Organic matter content was assumed to be 1%. Local increases in organic matter content are possible, but will not affect the surface erosion calculation greatly.

The slope length factor was derived using the average length of the slope perpendicular to the shoreline and the average slope of each polygon in the GIS layer. The following equation was then used to calculate LS (Springer and Lane, 1987):

$$LS = [(L/72.6)M]*[65.41*\sin2(S) + 4.56*\sin(S) + 0.65]$$

Where: $M = 0.6*[1-\exp(-35.835*s)]$

S = Average slope (degrees) of contributing area

s = slope (feet/feet) of contributing area

Slope lengths and slopes were derived for each polygon from the GIS map and U.S.G.S. topographic maps.

The vegetation factor was assumed to be 1.0, since the exposed shorelines are unvegetated.

The erosion control practice factor was assumed to be 1.0 since there are no plans for erosion control measures to be implemented.

Experience with the USLE has shown that it tends to overestimate soil erosion by not taking into account armoring that may occur at the surface as well as microtopography which can be an effective barrier to sediment delivery, particularly on gentle surfaces such as river terraces.

### J1–3 WAVE EROSION

Aerial photographs taken during the 1992 drawdown test show wave–cut terraces developed each day the reservoir level dropped. It was assumed that wave erosion would be significant in any drawdown especially because in March 1992 the wind was relatively calm.

Time constraints did not allow a detailed theoretical modeling of wave erosion. Indeed, such predictions of erosion have been seldom undertaken to date. Instead, an empirically–derived estimation was made, using the 1992 drawdown as the best–case scenario. Wave cut terraces were counted along each segment of the reservoir using the aerial photographs. Each segment was characterized as to how many terraces were eroded there. Then, assuming a geometry of the terraces similar to known, young terraces, the volume of sediment removed from the shoreline was calculated.

The general form of an immature wave cut terrace can be approximated by a triangle inverted and superimposed on the slope. The assumption leads to a slight overestimation of sediment removed, due to the accumulation of sediment at the toe of the terrace riser. The distance between the breaks in slope on two adjacent terraces was assumed to be about 3 feet for slopes greater than about 20%. Calculating the area of the triangle of sediment removed gives a cross–section area of about 2 square feet. As the slope of shorelines decreases, there is less surface area for the waves to impact, and therefore less erosion takes place. To account for this, the cross section area was adjusted downward. The decrease in surface area is exponential, rather than linear, so that the cross–sectional area removed from the shoreline profile decreases rapidly. The spreadsheet shows what these areas were assumed to be in the various slope classes (e.g., >20%, 15–20%, etc.). The cross–sectional area was then multiplied by the length of each of the polygons in the GIS layer, to get volume of material removed for each terrace. This was in turn multiplied by the number of terraces in the polygon.

Because the number of terraces varies with the amount of drawdown, and the amount of drawdown varies with the downstream distance, the number of terraces had to be adjusted to the position along the reservoir. The aerial photographs were used to estimate the average number of terraces in each segment. The number of terraces decreases rapidly above RM 135.

Because the amount of drawdown is greater in the natural river alternatives, the surface area affected by wave action is much larger than in the fixed drawdown alternatives. The number of terraces in the zone between MOP and the natural river bank was estimated based on the terrace spacing in the aerial photos.

The natural river alternatives would have greater wave erosion inputs to a point. That is, when the river level was reached, wave erosion would stop, and lateral stream bank erosion, if any, would begin. On the other hand, the fixed drawdown alternatives would have more wave erosion since there would still be a reservoir surface on which to generate waves. Because the reservoir sediments are unconsolidated, and because terraces develop rapidly (as shown during the 1992 drawdown), wave erosion tapers off rapidly. It was therefore assumed that wave erosion for the two month fixed drawdown would be only 30% greater than the natural river alternatives. The 4.5 month fixed drawdown was estimated to be about 1.5 times greater than the river alternatives.

Some of the sediment dislodged stays relatively close to the shore. The finer sediments become suspended.

The range of erosion possible was varied by simply multiplying the amounts of sediment by factors that account for various levels of wind. The base case was taken as the amount generated from each terrace in 1992. This was multiplied by 0.5 for the low wind scenario and by 1.5 for the high wind scenario. Although the moderate case is taken from a low–wind period (March 1992), it was deemed appropriate given that other assumptions tend to make the erosion estimate higher than it actually would be.

Because the geometrical assumptions of the volume removes from the banks overestimate erosion, the total wave erosion estimates were adjusted downward by 20%, the amount of area overestimated in the cross section of the wave cut terraces.

### J1–4 SLUMPING/SAPPING

Another route that delivers fines to the reservoir would be through slumping, which was very common in the 1992 drawdown. The potential for slumping is difficult to quantify, and the resulting estimate is expected to have a wide range of error. Sapping is similar in its effect, the difference being that sapping occurs on gentle slopes (as at the Alpowa Creek Delta) and is due to groundwater seepage and undermining of tributary banks.

The estimates presented in the slumping/sapping spreadsheet were derived empirically. The volumes of the slumps observed in 1992 was estimated by measuring the area dimensions directly from the photos. Depth was estimated by ground photos and by slump geometry knowledge. The amount of slumping in each segment was estimated and taken as the base case. Since much of the slumping probably occurs during and shortly after drawdown, it is not likely that length of drawdown period would significantly increase the amount slumped. The amount of drawdown would affect the quantity of slumping, but by how much exactly is not known. A drawdown to river level would expose many of the steep slopes that form terrace risers. Assuming these are blanketed with reservoir sediments as the terraces themselves are, a very unstable slope would result. It is therefore estimated that the river level drawdown would result in an amount of slumping about three times that in 1992 (the amount of drawdown is 3 times the 1992 drawdown, and the surface area exposed would be much higher). Drawdown to 705 feet would result in an amount of slumping slightly less than that in 1992 (drawdown to 697 feet). The slumping volume in 1992 was multiplied by the depth of drawdown in the 705 alternative to the 1992 drawdown depth, 0.78.

Three scenarios were developed by simply multiplying by coefficients representing variability in slumping of uncertain magnitude. The coefficients used were 0.5 for the minimum slumping and 1.5 for the extreme end of slumping.

### J1–5 TRIBUTARY INCISION

Although a relatively small component of erosion in 1992, the amount of incision could greatly increase if there were major storms during the drawdown period.

The amount of incision in 1992 was estimated by measuring length and width of channel incision into deltas using the aerial photographs. Depth was estimated by comparing the depth of the channel in stereo with the height or depth of familiar objects in the photos. At Alpowa Creek, depth of the incision was known from cross–sectional surveys.

Because of the lack of storm events during March 1992 drawdown test, the incision was caused by baseflow, and is the minimum to be expected. The amount of incision would also be increased with increased drawdown and prolonged drawdown, as area of delta exposed and the likelihood of storm events increases.

The amount of incision during the 1992 drawdown was taken as the best–case scenario for alternative 6c, fixed drawdown. The most probable case and worst–case scenarios were calculated by multiplying by 2 and 3, respectively. Note that the worst case scenario is only 50% more than the moderate case, where as the moderate case is 100% more than the best case. The represents the probability of the tributaries, with high runoff, reaching their older channels, which are probably less erodible.

The incision occurring in alternatives with longer drawdown duration was calculated by multiplying the baseflow incision by 1.5, representing a 50% increase in incision. The bulk of the incision would probably take place in the early part of the drawdown, as rainfall in the summer months is about half of that in the spring.

The drawdown to natural river alternatives would increase the amount of incision by twice that in the base case, since the area that would be exposed is about twice as much as is exposed in the fixed drawdown alternative. This is because the channels won't be that much deeper, but he length will be approximately two times that in the fixed drawdown alternatives.

### J1–6 WATER AND SEDIMENT DISCHARGE INPUTS FOR HEC 6 AND HEC 5Q

The total sediment eroded for each alternative and scenario was used to calculate the daily sediment inputs to the reservoir through shoreline erosion processes. To be accepted by HEC 6, input data was organized as though there were three major tributaries entering the mainstem. The three tributaries are actually the three segments which the reservoir was divided into. The model takes a discharge for each day and interpolates a corresponding sediment discharge from a designated range. Using the knowledge of reservoir processes, storm patterns in the reservoir area, and the results from the previous drawdown, dummy discharges were distributed that best mimicked how sediment would be eroded from the banks. The greatest amount of erosion takes place during the first few weeks of the drawdown, while the pool level is being lowered and shortly thereafter, due to slumping, wave erosion, and incision. For the fixed drawdown alternatives, low level erosion continues after the slumping and incision have dropped off, due to the continued effects of wave erosion. For all alternatives, brief episodes of high sediment input were shown scattered throughout the drawdown, but with more of them during the months of May and June. The May and June episodes represent storms, which will cause overland flow and erosion. There are more storms generally in May and June than in the other months.

Sediment input was calculated during the first year; the study of water quality and river sedimentation covers a span of 20 years, so it was necessary to estimate when or if the shoreline sediment inputs reached an equilibrium during that time. The main processes contributing to shoreline erosion, slumping, incision, and wave erosion, are thought to decrease rapidly during the drawdown. It also is probable that these processes would decrease in following years, as more and more sediment is removed. Lag deposits would develop, banks would eventually reach more stable profiles, and the original, pre–reservoir sediments would be reached. The pre–reservoir sediments would be more cohesive and possibly coarser and more difficult to transport by overland flow.

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# ATTACHMENT J2

# TOXIC WATER QUALITY PARAMETER SCREENING

EBASCO MEMORANDUM

To: Tom Martin

From: Roger Kadeg

Subject: SOR WQ Parameters Summary of Selection Process

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Per our discussions, I have reviewed the existing Columbia drainage basin water quality data you provided, in an effort to identify a second tier of approximately 20 contaminants of concern from the universe of potential compounds. Following is a brief summary of the selection process used to develop the proposed list.

Upon first review of the data, it was apparent that the EPA STORET data base identified the most diverse and broadest range of potential contaminants. Therefore, these data were selected as an initial starting point. The target list of over 100 compounds was reviewed for any contaminants that showed "hits" (concentrations above detection limits) in any of the media tested (typically water, sediment or tissue). General physical parameters such as pH, hardness, TDS or conductivity were excluded. Also excluded were nutrients (e.g. phosphates, nitrates, and related compounds like ammonia) that will be included as part of the model, temperature and dissolved oxygen that will be modeled elsewhere, and major ionic components (e.g. calcium, sodium, chlorides, sulfates, etc.) that are best indicated by TDS or conductivity, and traditionally not considered as top priority toxicants. This screening for "hits" left 55 compounds, groups or isomers for consideration. Note that, based on the provided data, some compound groups on this list are segregated (e.g. PCBs by Aroclor), while a couple remain as groups (e.g. phenols, chlordane).

To further screen the list of 55 compounds, a vectorial algorithm described by Halfon (1989) was employed. This procedure ranks toxic contaminants according to pre–specified criteria (which are typically weighted). The ranking output can be displayed with Hasse diagrams, a tool adopted from lattice theory. (These diagrams place the compounds into groups, and show the presence of all contradictions with lines, useful information that is usually lost on a typical spreadsheet screening. Genealogical trees are a special case of Hasse diagram). A key advantage of this procedure is that, once the screening criteria are specified (e.g. site concentrations, chemical properties), the process is objective and will identify any subtle counter–intuitive factors, as well as confirming best professional judgments. The various criteria can be switched on or off and weighted to analyze for sensitivity and "what–if " scenarios.

The selection criteria for the vectorial screening used three site specific (i.e. concentration data), and three chemical specific ( toxicological/physical properties) criteria. More selection criteria could be employed, but as criteria increase, the selection contradictions tend to increase, collapsing the compounds into two or three indistinguishable groups. The specific criteria are as follows:

1. Frequency. Expressed as percentage of "hits" vs. number of measurements, assigned to a weighted scale of 1 to 10.
2. Water Quality Criteria exceedence ratio. Ratio of maximum observed value to Federal Water Quality Criteria, assigned to a weighted scale of 1 to 10. An indication of ecological toxicity.
3. Mean observed concentrations. Assigned to a weighted scale of 1–5.
4. Log of Octanol–Water Partitioning Coefficient (Kow). An indication of partitioning to sediment /organic carbon and therefore persistence.
5. Human Toxicity. Toxicity based on oral chronic values for IRIS cancer slope factor or RfD for non carcinogens, adjusted to a weighted scale of 1–10.
6. Bioaccumulation Potential. Based on fish BCF data, assigned to a weighted scale of 1–10. An indication of potential presence in food chain.

I have attached a list of the 55 compounds together with the assigned criteria values according to the numerical order given above.

The screening process resulted in delineation of a total of six groups (ranking levels), with three groups containing the bulk of compounds. Note that any compound within a group is not comparable to another within the same group; that is, given the criteria, there is no clear basis to select one over another. The top two groups are as follows (with group 1 top priority):

Group 1 – aldrin, alpha–BHC, beryllium, bis–2–ethylhexylphthalate, chlordane, copper, DDE, DDT, dieldrin, heptachlor, HCB (hexachlorobenzene), Aroclor 1248 (PCB), Aroclor 1260 (PCB), toxaphene, and zinc (15 total)

Group 2 – arsenic, benzo(k)fluoranthene, benzo(a )pyrene, beta–BHC, gamma–BHC (Lindane), cyanide, DDD, endrin, fluoranthene, heptachlor epoxide, lead, mercury, Aroclor 1242 (PCB), Aroclor 1254 (PCB), pentachlorophenol, and silver (16 total).

If one deletes the chemical /human toxicological criteria, and uses only the first three site–specific criteria, twelve groups are delineated; the top five groups are as follows:

Group 1 – beryllium, bis–2–ethylhexylphthalate, copper and toxaphene (4 total)

Group 2 – alpha–BHC, chlordane, DDD, DDE and zinc (5 total)

Group 3 – beta–BHC, n–butylbenzylphthalate, lead and cyanide (4 total)

Group 4 – heptachlor, heptachlor epoxide, HCB and Aroclor 1254 (PCB) (4 total)

Group 5 – delta–BHC, cadmium, 1,3–dichloropropene, endrin, manganese, silver and pentachlorophenol (7 total).

Based on our further evaluation Friday (April 30) of these results, it seems best to select the following four compounds for modeling:

> one metal – copper (alternately beryllium, lead or zinc),
>
> PCBs – either total or priority to Aroclors 1242, 1248, 1254 and 1260
>
> one historic use pesticide – DDT family (alternately aldrin–endrin–dieldrin family)
>
> one additional pesticide/herbicide – one of either chlordane, toxaphene, or BHC family.

The final selection factors to decide which alternate(s) would be based upon geographic distribution and size and usability of the data sets, based upon your compilation of all data. One could model a common PAH, but given the reported levels and the objective screening, they are clearly of secondary importance relative to the pesticide/herbicide concentrations reported in the tissue samples

A master list of specifically twenty compounds is more difficult to recommend, given the screening results. If one lumps the families of groups 1 and 2 for the full six–criteria screen, one obtains the following 21 compounds:

> aldrin family, arsenic, BHC family, benzo(k)fluoranthene, benzo(a)pyrene, beryllium, bis–2–ethylhexylphthalate, chlordane, copper, cyanide, DDT family, fluoranthene, heptachlors, HCB, lead, mercury, PCBs, pentachlorophenol, silver, toxaphene and zinc.

I would suggest this list, with two possible additions, as the initial "twenty compound" working list. I see nothing from a chemistry viewpoint that compels me to reduce this list further. The two additional compounds are TCDD and fluoride. The preliminary data provided to me had no "hits" for dioxins/furans, or the critical TCDD isomer. However, the detection limits were high, and I believe these compounds are problematic in some areas of the basin. Therefore, we should consider TCDD in spite of the lack of STORET data. Of lessor concern, we may wish to add the fluoride ion, associated with the aluminum industry.

If forced to obtain exactly 20 compounds, I would first select the compound with the best data set (based on frequency of measurements and geographic distribution) from each family to represent the entire family. I would then delete in the following order: bis–2–ethylhexylphthalate (it is ubiquitous and rarely remediated), fluoranthene (of least concern of the listed PAHs), arsenic (levels typically near background), cyanide (degrades, not persistent) and beryllium (not frequently found).

One last compound group that was not considered is the exotic radio nuclides. It is known that past Hanford Reservation activities has distributed these compounds throughout the middle and lower Columbia system. These elements are critical, but due to their unique nature, really deserve a separate investigation. For the initial purposes of the present investigation, one may assume that the detected beryllium sources are likely associated with the Hanford activities and can serve as a surrogate indicator of the radio nuclides. This assumption should be verified (based on distribution of "hits"), and if not true, a radio nuclide indicator should be added to the list.

# TECHNICAL EXHIBIT K

# USE OF EXISTING HEC–5Q MODEL RESULTS FOR NEW SOR ALTERNATIVES

**FOSTER WHEELER ENVIRONMENTAL CORPORATION**

April 4, 1995
FWBEL-BPA-SOR-95L-012

Dr. Bolyvong Tanovan
SOR Water Quality Work Group Chairman
Army Corps of Engineers, North Pacific Division
U.S. Customs House
220 NW 8th
Portland, Oregon 97208-2870

Dear Bolyvong:

Enclosed is a brief memo that addresses the need to conduct additional full-scale water quality modeling of the new SOR alternatives: SOS 5(c), 9(a,b,c) and the preferred alternative. Considering that sediment related impacts are high priority water quality issues, I analyzed the reservoir bed scouring potential for these new alternatives.

I attempted to use the existing full-scale model results to estimate sediment concentrations for the new SOSs. Model results for SOS 6b, SOS 2a, and SOS 6a can be used represent SOS 9a, SOS 9b and SOS 9c, respectively. No one existing SOS analysis could represent SOS 5c. However, the sediment exceedence curve for SOS 5c was roughly estimated by extrapolating from the model results of SOS 5a and SOS 5c.

Several simplifying assumptions were made to estimate sediment exceedences for SOS 5c. The accuracy of this estimate is highly uncertain. However, the SOR decision-makers may not require a more accurate estimate that would result from further investigation. The enclosed memo explains how the assumptions affect the certainty of the estimates, then suggests additional work that could be done to reduce this uncertainty.

Please review the enclosed memo and send me your comments soon.

Thank you.

Sincerely,

Tom Martin

Tom Martin

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FOSTER WHEELER ENVIRONMENTAL CORPORATION

## MEMORANDUM

**FROM:** Tom Martin
**TO:** Dr. Bolyvong Tanovan, SOR Water Quality Work Group Chairman
**DATE:** April 4, 1995
**SUBJECT:** Use of existing HEC-5Q model results for new SOR alternatives

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This memo summarizes the preliminary water quality impact analysis of five new SOSs that were developed for SOR since the release of the Draft EIS: SOS 5c, SOSs 9a, 9b and 9c, and the preferred alternative (SOS PA). The SOR Water Quality Work Group placed the highest priority on total dissolved gas, temperature and sediment transport issues. Only sediment transport issues facing the new SOR alternatives are addressed here. Recall that metal, pesticide and other organic contaminants exist in lower Snake River reservoir bottom material, and that river operation induced sediment transport would impact the fate and transport of these constituents. The analysis concentrated on comparing flow and drawdown specifications between the Draft EIS and new SOSs, and identifying potential differences in Snake River velocity during drawdowns. The only new alternative studied that is not comparable to any of the Draft EIS SOSs is SOS 5c due to its full year drawdown. This memo also describes a technique used to estimate SOS 5c sediment transport and its limitations. Additional work that would improve the accuracy of the SOS 5c sediment transport estimates is suggested.

## DRAWDOWN AND FLOW COMPARISONS

All SOS 9 alternatives and SOS PA would have sediment transport impacts that are similar to one or more of the SOSs evaluated for the Draft EIS. This is due to the similarity between the previous and new SOS flow and drawdown specifications. SOS 9b and SOS PA do not specify Snake River drawdown, and therefore are similar to SOS 2a. Even though flow targets are specified for SOS 9b and not for SOS 2a, their sediment transport impacts are assumed to be the same because neither SOS specifies drawdown. This assumption was adopted by the SOR Water Quality Work Group for the Draft EIS analysis, and therefore should also apply to this analysis. SOS 9c specifies a 4.5 month partial drawdown of the four lower Snake River reservoirs and no flow target at Lower Granite, and therefore is similar to SOS 6a.

SOS 9a included both a 4.5 month partial drawdown of the lower Snake River reservoirs and flow targets at Lower Granite with flow augmentation from upstream sources. SOS 6b specified the same drawdown schedule as SOS 9a, but without the flow target and augmentation. There is a potential for SOS 9a having greater sediment concentrations than

6b, given greater SOS 9a flows and equal drawdowns. SOS 9a velocities would be greater than SOS 6b. This should cause more reservoir bottom sediments to be scoured.

## SOS 9A VELOCITY ANALYSIS

Figures 1 through 3 show the estimated Snake River velocity at Clarkston (river mile 139) for a high, medium and low flow year, respectively. The velocity was calculated using the revised SOR hydroregulation flows and end elevations for Lower Granite, and reservoir geometry data from the SOR HEC-5Q model (RMA, 1993) and the 1992 Reservoir Drawdown Test (Lower Granite and Little Goose Dams) Report (Corps, 1993). The cross-sectional area at river mile 139 was assumed to be trapezoidal in shape, with a base elevation of 695 feet, a 400 foot base width, and a 1:7.5 side slope. For non-drawdown months, the velocity equalled the flow divided by the cross-sectional area (given the end elevation). For drawdown months, the velocity was found from a flow-velocity rating table that was derived using Manning's Equation ($n=0.035$, and $s=0.00044$). The table entries were calculated using the trapezoidal cross-section given a series of water surface elevations ranging from 700 to 735 in 5 foot increments. During drawdown, the most scour would be expected at the head of each lower Snake River reservoir because the river would be free-flowing and scouring the delta deposits.

Predominantly, the SOS 9a velocity is greater than the SOS 6b velocity during the drawdown period (15-April to 31-August). The greatest difference would be during the last half of April in a low flow year. However, on a percentage basis, the overall velocity difference is small. Therefore, SOS 6b sediment concentrations are representative of SOS 9b.

## SOS 5C SEDIMENT TRANSPORT ESTIMATION

The lower Snake River would be drawn down to natural river level throughout the entire year for SOS 5c. The SOS 5a and SOS 5b specified a 2 month and 4.5 month natural river level drawdown period starting April 15, respectively. Neither previous SOS 5 alternative could, by itself, represent the sediment transport generated by year-round drawdown. However, the silt concentration exceedence curve for SOS 5c could be estimated by extrapolating from the SOS 5a and SOS 5b curves.

The SOS 5a to SOS 5b increase in high flow condition percent exceedence was calculated, then pro-rated on a per-month basis. This rate was applied over a 12 month period to calculate the exceedence increase from SOS 5a to SOS 5c. Figure 4 shows the estimated SOS 5c silt concentration exceedence curve. For SOS 5c, 25 mg/l would be exceeded 41 percent of the time; 50 mg/l exceeded at 30 percent; 150 mg/l exceeded at 13 percent; and 500 mg/l less at than 5 percent.

The above method assumes that the sediment exceedence increases uniformly from one month to the next. However, this is not the case for a typical year in the Columbia River basin. The drawdown period from which the exceedences were extrapolated included from

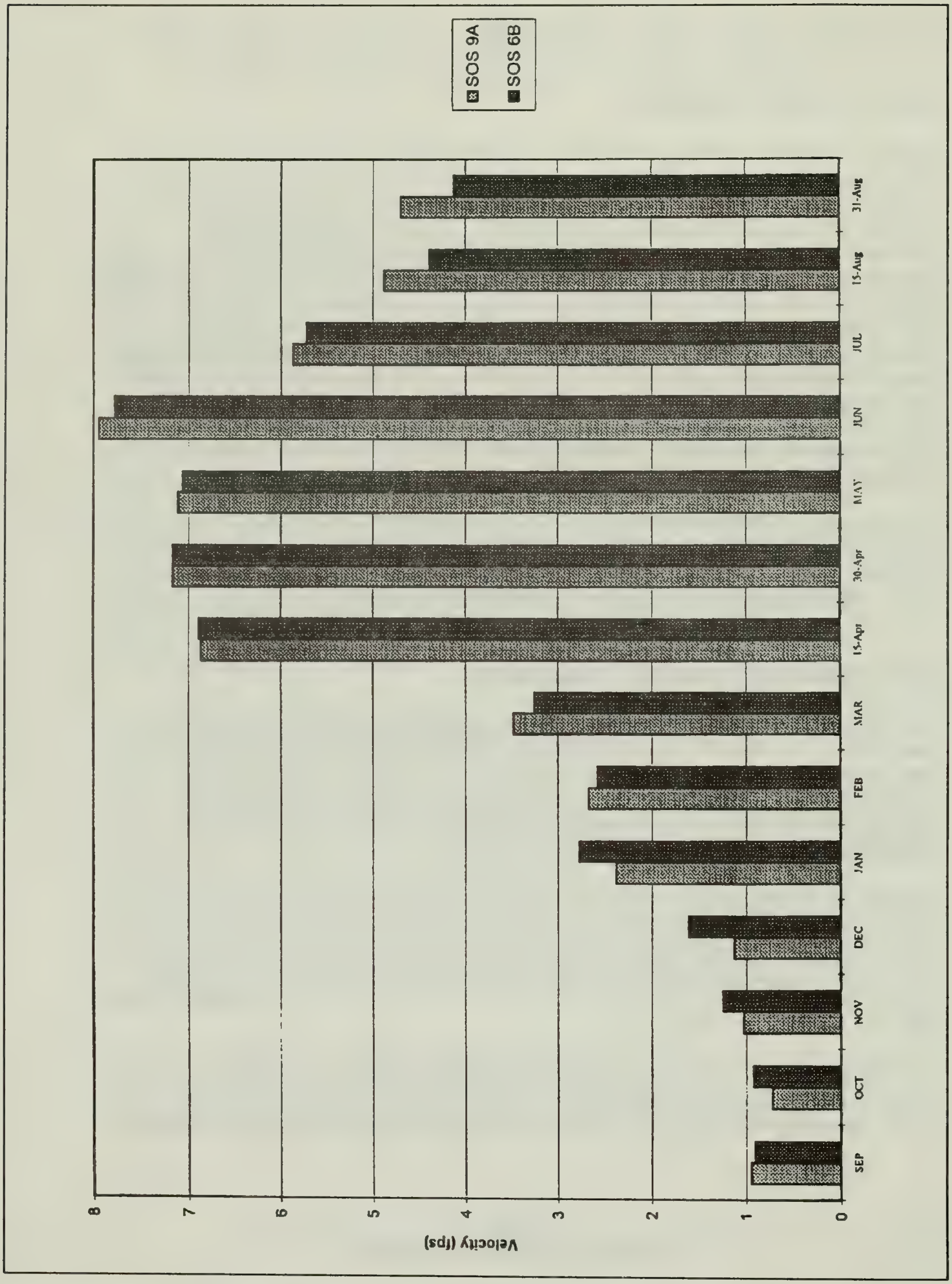

**Figure K–1. Snake River Velocity at Clarkston, WA High Flow Year (1974)**

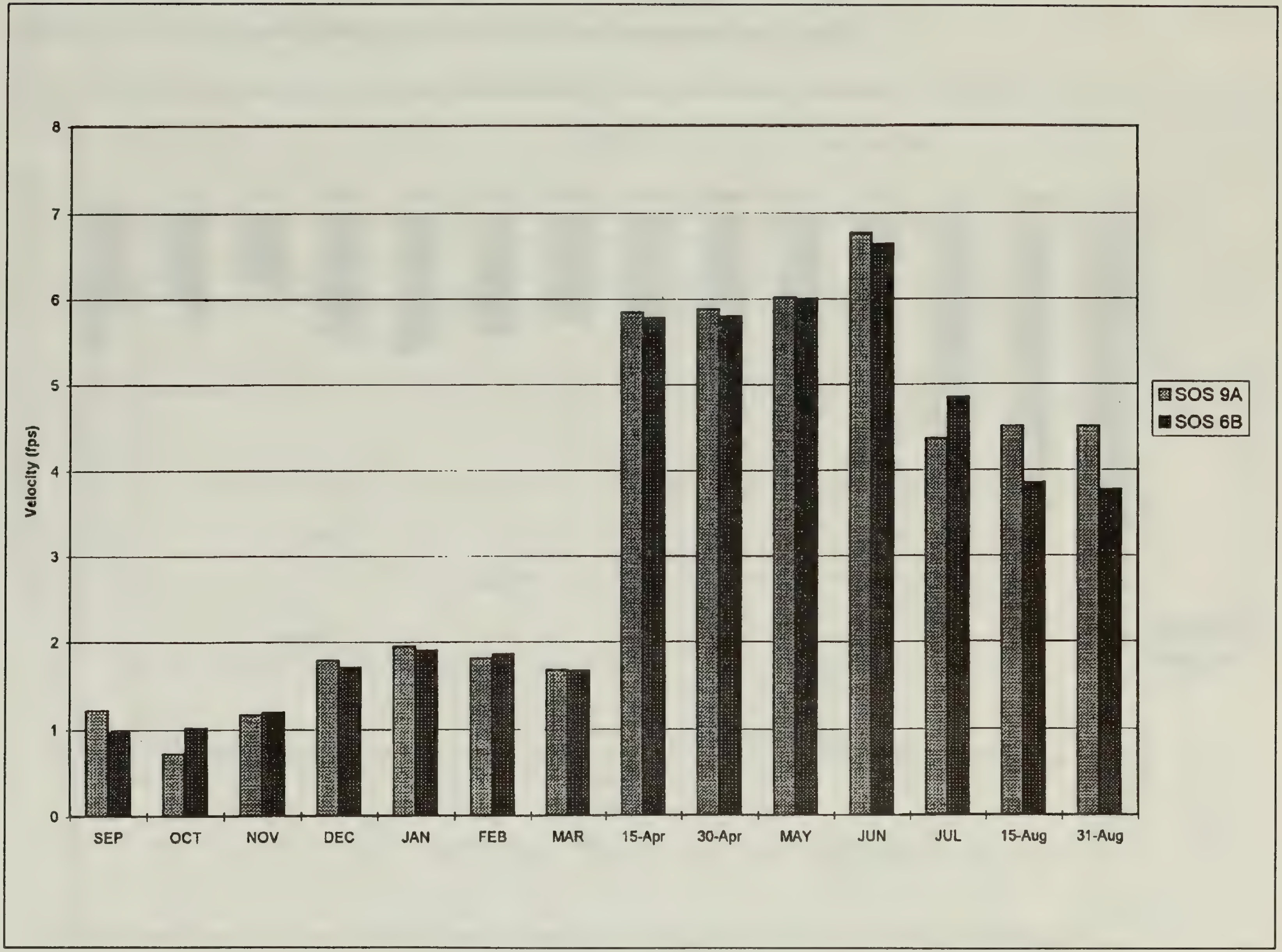

Figure K–2. Snake River Velocity at Clarkston, WA Medium Flow Year (1959)

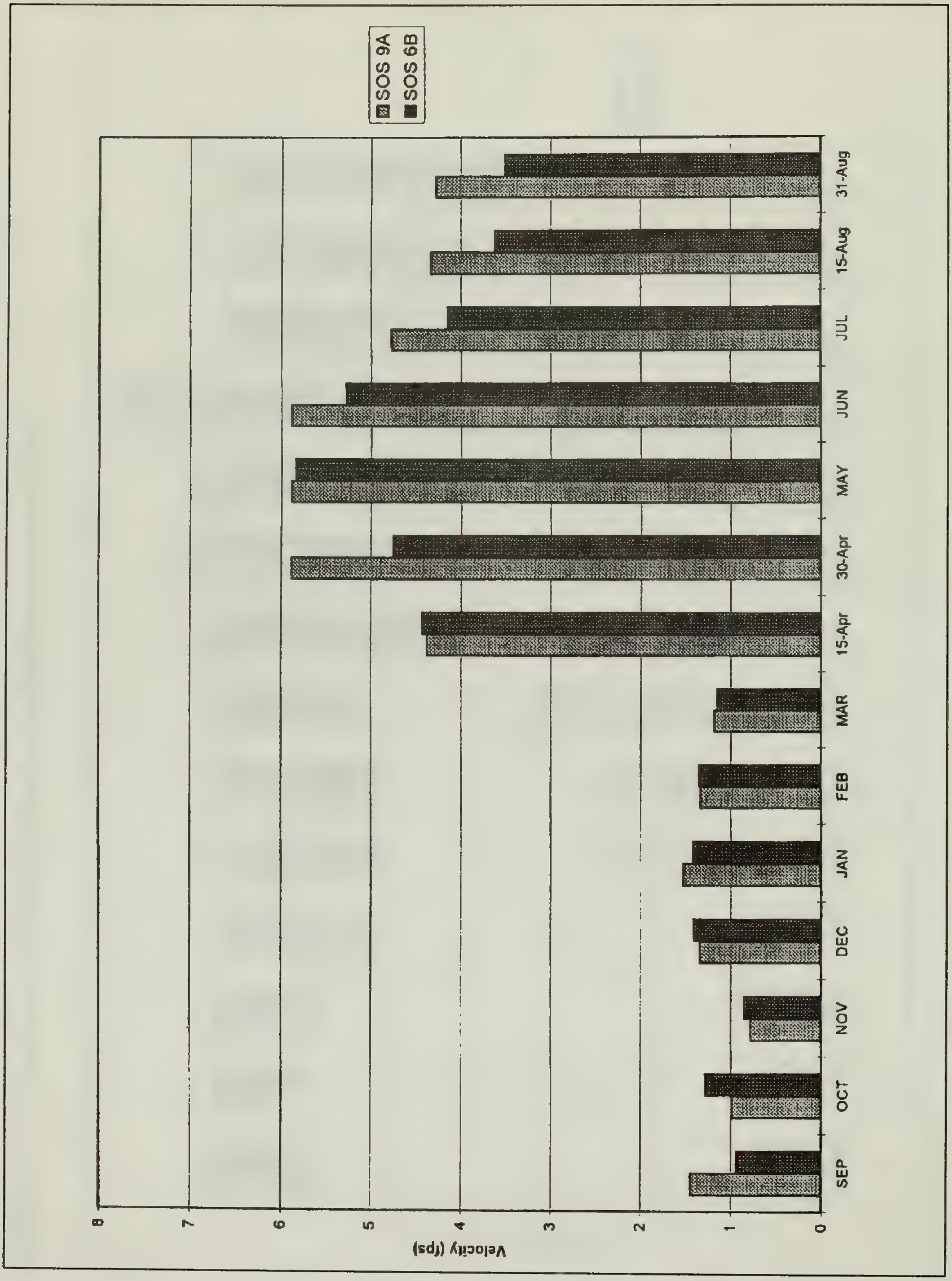

**Figure K–3.** Snake River Velocity at Clarkston, WA Low Flow Year (1973)

EBASCO SERVICES INCORPORATED

BY THM DATE 3/30/95 SHEET ____ OF ____
CHKD. BY ____ DATE ____ OFS NO. ____ DEPT. NO. ____
CLIENT ACOE / BPA
PROJECT Columbia River SOR
SUBJECT SOS 5C Estimated Sediment Concentration

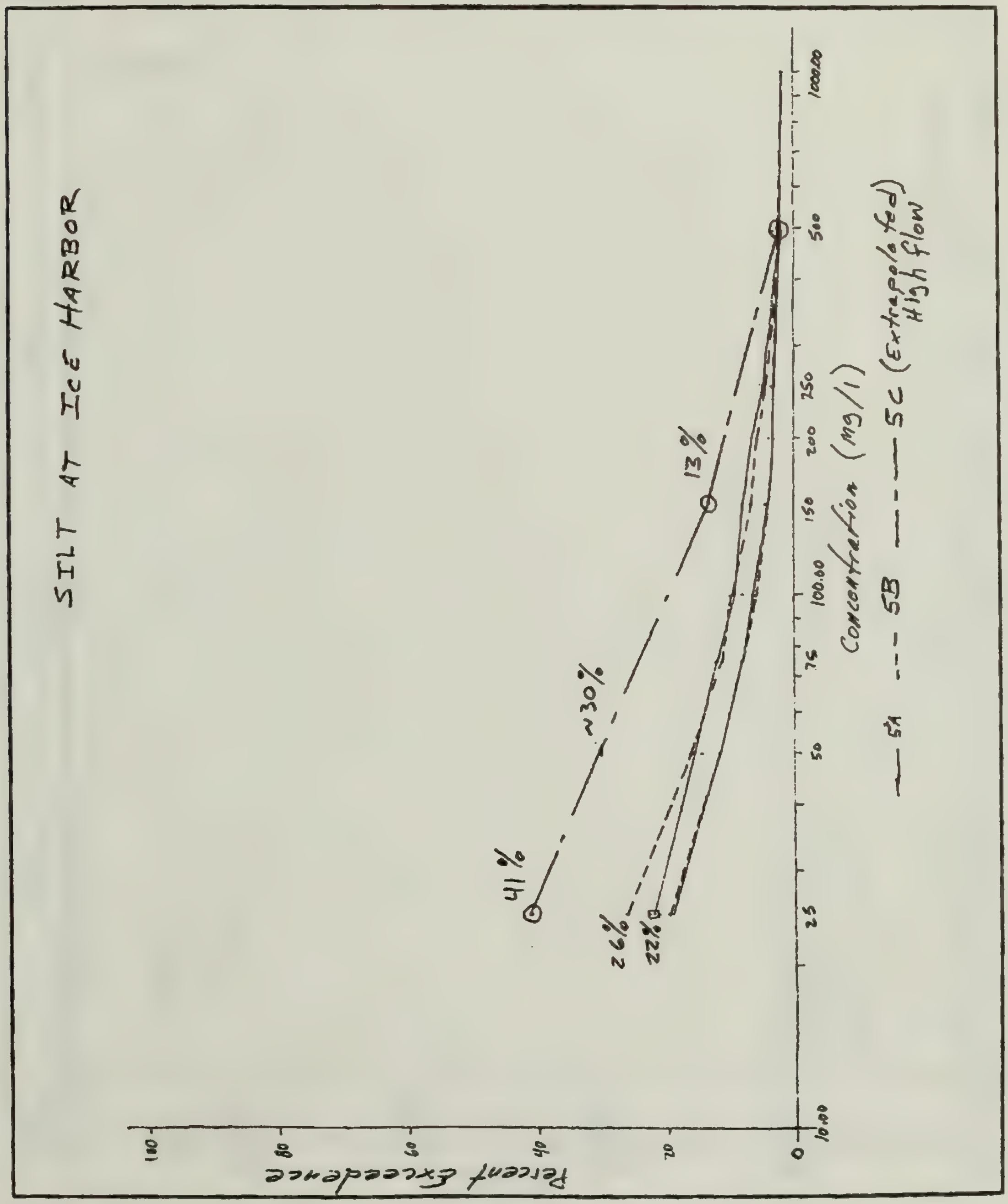

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**Figure K–4. EBASCO Services Incorporated**

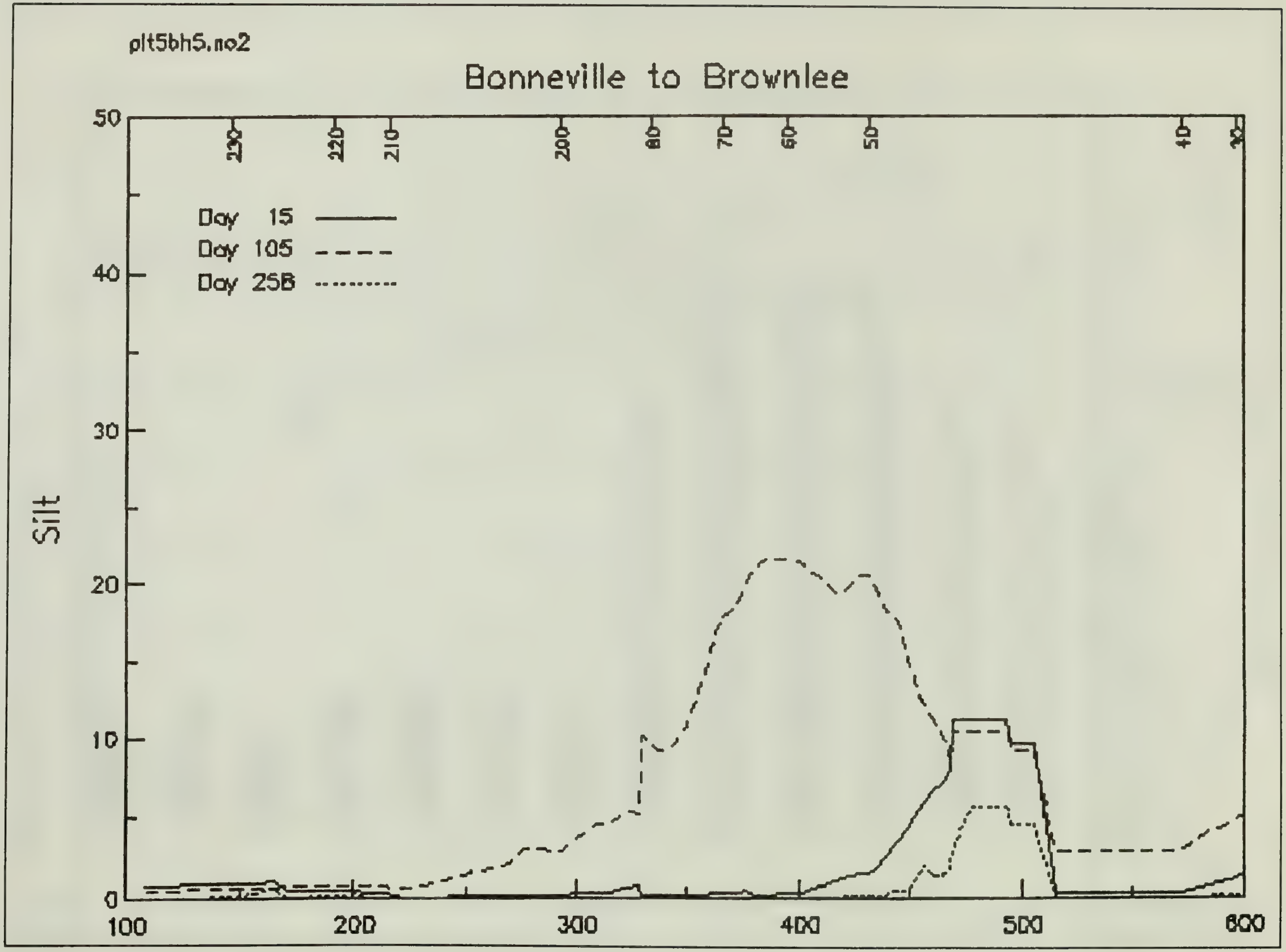

Figure K–5. Silt Concentration Profiles from Bonneville Dame to Brownlee Dam

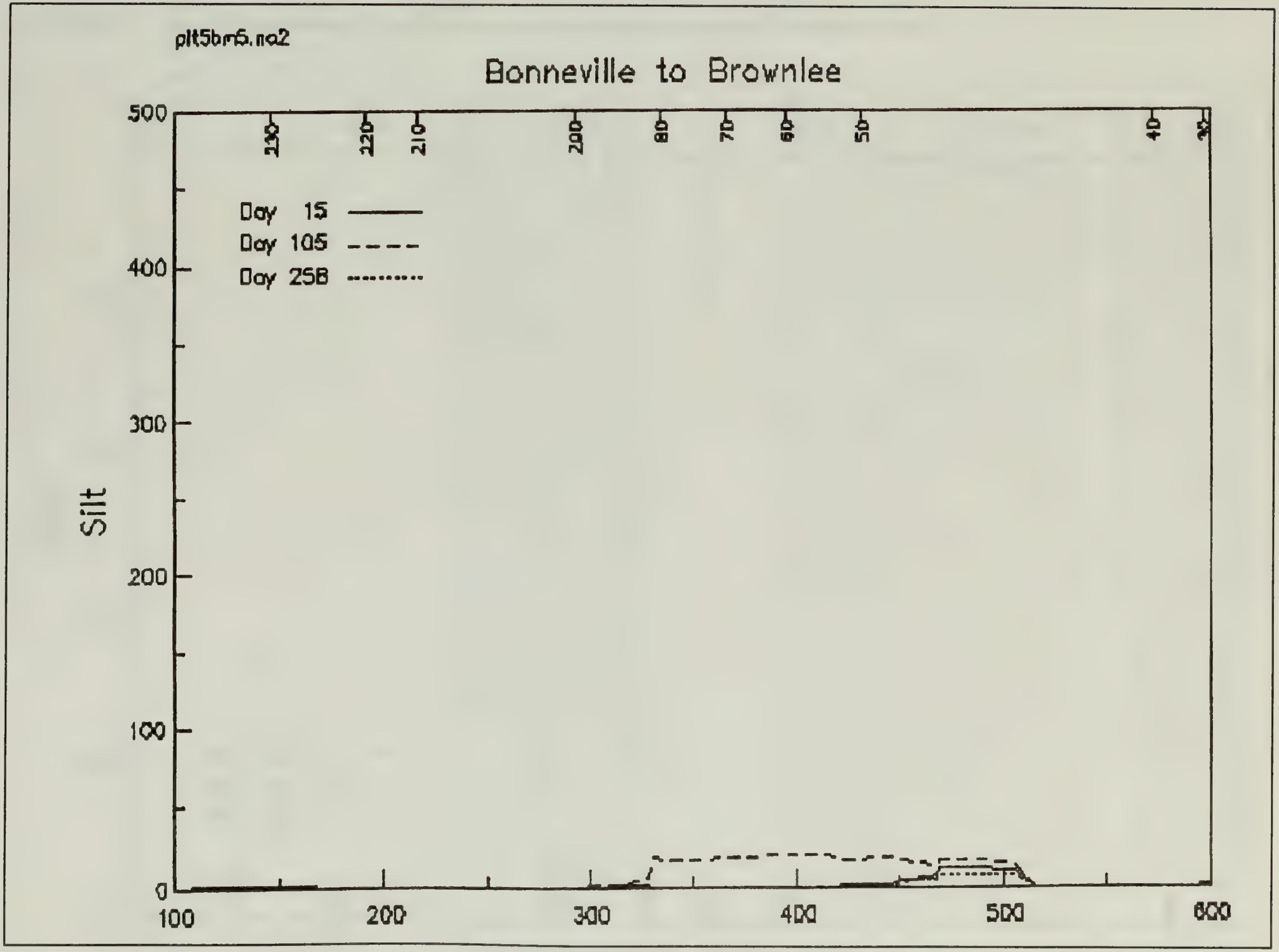

Figure K–6. Silt Concentration Profiles from Bonneville Dame to Brownlee Dam

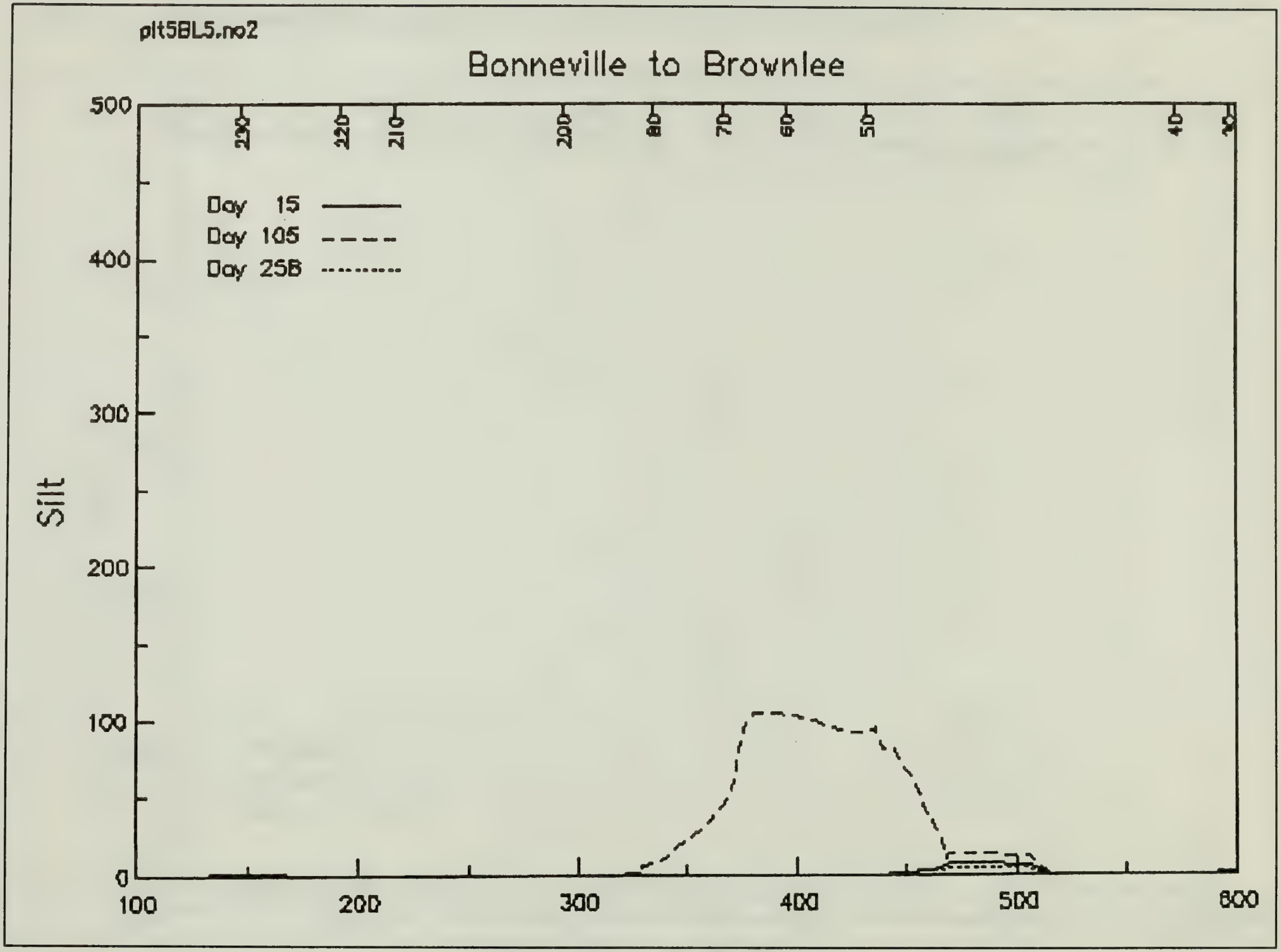

Figure K–7. Silt Concentration Profiles from Bonneville Dame to Brownlee Dam

15 April to 31 August. The remainder of the year is typically wetter. Precipitation during the fall and winter would cause greater amounts of exposed reservoir bank erosion than during the spring and summer drawdown period. The flow velocity would also be different during the fall and winter. Consequently, the lower Snake River, operating under a 12 month natural river drawdown, would continuously receive sediment from scouring of reservoir bottoms and erosion of exposed reservoir banks.

For the Draft EIS, we concluded that essentially all of the reservoir bottom sediments in the lower Snake River would be scoured away within 5 years. Figures 5 to 7 show the silt concentration profiles along the Columbia and Snake Rivers, from Bonneville Dam to Brownlee Dam, for SOS 5b during the fifth year of drawdown, under high, medium and low flow conditions, respectively. In Figures 5 and 6, the high and medium flow condition profiles show that there is a small increase in sediment concentrations downstream of the confluence of the Snake and Clearwater Rivers (about river mile 475 on the horizontal axis). This indicates that the river would have scoured down to its original channel, and natural river sediment transport had be reached. Only reservoir bank erosion would increase the sediment transport after 5 years, under high and medium flow conditions. Under low flow conditions (see Figure 7), maximum sediment concentrations in the lower Snake River would persist at about 100 mg/l. It would take longer than 5 years to scour away the lower Snake River reservoir bottom sediments under low flow conditions.

## RECOMMENDATIONS

It is difficult to predict the exceedence of sediment concentrations and the number of years required to scour down to the natural channel thalweg without model simulations. A 12-month drawdown would only have one extreme scour event during the first drawdown, compared to once a year for spring-summer drawdowns. On the other hand, the 12-month natural river drawdown would scour more continuously than the spring-summer drawdowns. It is unclear whether the persistence of elevated levels of sediment transport (and concentrations of metals, organics and nutrients) throughout the lower Snake River would be longer for a 12-month drawdown compared to the spring-summer drawdown. Further full-scale model analysis using HEC-6 and HEC-5Q would provide a better estimate than shown in Figure 4.

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